THE MONTANA SUPERINSULATION PROJECT:
Project History and Results

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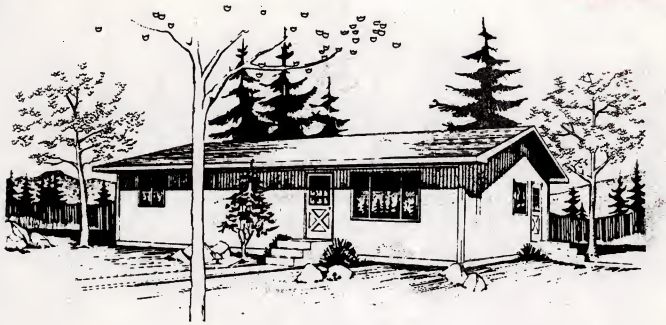

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INTRODUCTION

This publication describes the Montana Superinsulation Project, 1984-86, sponsored by the Montana Department of Natural Resources and Conservation, through the Montana Renewable Energy and Conservation Program. DNRC's Energy Division is charged with promoting ways Montanans can save energy and use renewable energy resources through a variety of programs.

The National Center for Appropriate Technology, a national organization with headquarters in Butte, designed and managed the program. NCAT has been researching superinsulation since 1979, as well as weatherization and other aspects of renewable energy and conservation. NCAT was founded in 1976 to develop these resources for low-income Americans.

This publication is designed to accompany a slide show prepared for the state under this project. Both the slide show and the publication are aimed at reporting on this innovative project, as well as describing the technologies and methods known as superinsulation.

This project had several key goals: to inform those interested in this new approach; to educate interested builders; and to perform research detailed enough to help develop useful tools for the future design of these types of houses.

[illegible] IN [illegible]?

WHAT IS SUPERINSULATION?

Three main differences separate a superinsulated home from one that is conventionally built.

The first is greater insulation levels. Extra insulation is added from the basement to the ceiling, and it's installed carefully and uniformly to get the full value from the material purchased. The walls and ceiling are built somewhat differently to accommodate the extra insulation.

A continuous air-vapor barrier is installed to ensure that the building envelope is as airtight as possible and that the insulation is protected from moisture generated in the house. This air-vapor barrier is typically made from a tough plastic, installed under the wall board. Some builders are currently experimenting with installing sheetrock tightly to get the same effect.

The newest element is a ventilation system that recovers heat, to provide continuous fresh air without the heat loss. Conventional houses rely on cracks and leaks in the building shell to ventilate the house when windows are not open. The superinsulated house uses a controlled ventilation system to do this job.

These features combine to reduce heat losses to such a low level that heat produced by sources inside the house, such as appliances, lights, people and the sun provide the bulk of the

heat for the house. So a much smaller heating system is needed, usually only for the coldest days.

WHY SUPERINSULATION?

Superinsulation has its roots in passive solar. In response to the energy crisis of the 1970s, researchers looked for ways to harness the sun's energy to heat homes. Passive solar methods in this period required large amounts of south-facing glass, and a building site that had access to the sun. In addition, it was a fairly complex task to design a house during this period that looked like those people were accustomed to.

The Canadians in our neighboring province of Saskatchewan took a more dramatic approach in 1977-78, by emphasizing conservation as well as passive solar. In a ground-breaking research and demonstration house, they tested the concept of adding much more insulation, along with making the building shell extremely tight. To supply fresh air, a controlled ventilation system with heat recovery was installed.

Passive solar would still play a role, but windows could be more conventionally sized. The comfort and extremely low space heating costs reported from the Saskatchewan Conservation House caused a wave of excitement and interest in the new methods, both in Canada and the United States.

The design flexibility allowed by superinsulation sparked

interest in cold-climate states, where builders began trying to use the methods. In 1980-82, Minnesota started a state-sponsored incentive program to contrast passive solar construction with superinsulation.

In the same time frame, Canada started the R-2000 program, which offers training and computer design assistance as well as incentives to builders to build superinsulated houses.

The NCAT Houseplans

In 1979-80, NCAT did research comparing conservation and solar. Researchers developed a computer model, studied test cells and performed other studies to assist in the work of designing the most cost-effective methods to build the new type of housing for cold climates.

This research resulted in a series of house plans that are unique in that they go far beyond what is conventionally offered in stock house plans. The purpose of the NCAT plan effort was to share the knowledge gained through the research in a graphic form that could be immediately used by those who wanted to safely use the new methods.

Another goal of the plan effort was to provide a clear technical statement that could be studied in greater depth. Since the development of four types of house plans, more than 1,500 sets have been distributed to those interested in studying

the methods or building the houses and trying the technology for themselves.

Another key part of the NCAT house plan effort was cost. The plans were designed to reduce the cost of the conservation features by the construction sequence of the house, and by careful attention to other aspects of the construction process. Because of NCAT's emphasis on the low-income homeowner or occupant, cost and cost-effectiveness were studied at great length, with the goal being to design a house that had superinsulation features at no added cost over a similar, conventionally built house.

SUPERINSULATION FOR MONTANA

Montanans currently spend nearly one-half billion dollars annually to heat their homes in the wintertime. Superinsulation is among the most promising approaches to dramatically reduce heating costs in new construction, while improving comfort in Montana's severe winters.

Conservation built into a house is less expensive and more effective than going back to weatherize the house after it is built.

Regionally, the importance of conservation was clearly stated by the Northwest Power Planning Council, which in 1984 and 1986 prepared electric power plans for the Pacific Northwest that cover four states including Western Montana. A key part

of the plans are the Model Conservation Standards for residential buildings, standards designed to promote conservation in new houses built throughout the region.

The Model Conservation Standards were designed to promote homes that would be an estimated 60 percent more efficient than average homes built by today's methods. To test the cost and energy performance of the new standards, the Bonneville Power Administration developed a program under which more than 400 energy efficient houses were built regionwide. More than 60 of these homes were built in the BPA service area in Western Montana. The program encouraged builders to try a number of methods to reach the predicted energy performance goal of the standards.

In general, options outlined in the Model Conservation Standards include elements of superinsulation, but the insulation levels needed to meet the performance goals tend to be somewhat lower than those shown in the NCAT house plans or those typically practiced in superinsulation in cold climates.

Because BPA's program was limited to Western Montana, and because these houses were not part of a planned research experiment, NCAT proposed to build five houses in Eastern Montana from one of the detailed NCAT plans.

Like the BPA houses, the Montana project homes would be all-electric.

PROJECT GOALS

NCAT proposed the project to accomplish three goals: information, education and detailed field research. Since superinsulation was so new to most Montanans, it was important that accurate information be offered to all those interested in the methods - builders, buyers, lenders, realtors, suppliers and inspectors.

Through its experience of dealing with builders across the country through the houseplan effort, NCAT had a clear understanding of the need for this information - in other areas of the country, the demand for the new technologies and methods were outstripping the industry's ability to provide it, and problems were occurring. Also the term "energy efficient" had lost meaning in the process, and it was important to provide information to help people in the shelter industry evaluate what was meant by this term.

These experiences led to the development of a conservative, research-based training program for builders that is designed to show methods that are not a great change from current building practices. It is easiest to learn new methods in terms of what is already known.

Finally, researchers needed study comprehensive enough to provide critically needed verification and understanding of the methods, so that the superinsulation approach could be better

understood and compared with current construction methods.

The goal of the research was not to provide a simple check on whether the technologies and methods work - there was already strong evidence to show that they can. Rather, the purpose was to learn more about why and how the methods work, explore how this system works in Montana, and learn what improvements would be recommended for the future. With all the enthusiasm over the new methods and the promise they hold, many people were missing the fact that so little detailed research was being done that it was becoming impossible to separate myth from reality.

Work in the early 1980s showed that superinsulation would generally perform better than passive solar alone, but until the Montana project, a research project hadn't been done with a sample of thermally identical houses to see the range of occupant effects or to verify that the performance measured was really something to bank on. The performance of the Montana homes would also provide a comparison with the demonstration homes built in Western Montana by BPA.

PROJECT HISTORY

The Montana Superinsulation Project started in late spring 1984 with an information campaign to builders and buyers. Evening seminars were provided in Billings, Great Falls, Miles

City, Glasgow and Lewistown. These cities were targeted because federal weather stations are located in them. These weather stations provide data that would be important to the research effort. NCAT also provided information about the project through radio and newspaper interviews.

EDUCATING BUILDERS

No financial incentives were offered to builders. Instead, education was offered, such as detailed training by the NCAT team, and participation in the measurement effort.

Builders and crew members from all five project cities came to NCAT's offices for a two-day seminar on the project and the house plans under study in the project. Part of the training focused on making the houses as similar as possible from a thermal standpoint, while allowing builders enough flexibility to meet buyers' tastes and preferences.

Not all the original project builders could secure construction financing due to a sluggish housing market in Eastern Montana. Two houses being built independently from the same NCAT houseplans were added to the program in Great Falls.

The final group of houses included three in Great Falls, one in Lewistown and one in Billings. The participating builders included an owner-builder couple with no prior building experience and a builder who had built a superinsulated house once before.

This difference in experience level gave the project team a chance to see how well the house plans work as a tool to transfer the new methods. The two new builders who joined the program were not given special training; the plans and a companion manual developed by NCAT were their guides. As a part of the education aspect of the project, NCAT supplied DNRC with 1,000 copies of this manual for distribution to interested builders across the state.

During the construction phase, NCAT staff were on call to answer any questions about the construction process or the research aspects of the program.

Construction Phase

Designed for families who want plenty of space at a modest cost, the project house plan is for a 1,288 square foot ranch style house with three bedrooms, two baths and a full basement that can be finished to double the space. For the Montana project, the builders were asked to at least thermally finish the basements, meaning that the energy features such as the insulation and the vapor barrier would be added. As it turned out, most builders completely finished the basements for the extra living space.

Each builder took a different approach to building the houses and finishing them. The owner-builder built the house on

weekends over three months.

In another case, one of the builders pre-fabricated parts of the house in his shop, enabling him to get the house closed in rapidly during cold-weather construction in January.

The three Great Falls houses were finished in the same time frame, and the other two were completed in January and February 1985.

The finished houses range from comfortably simple to luxurious - one even sports a basement hot tub. From the outside, it is difficult to tell that these houses were built from the same plan, but the energy features remained constant.

Energy Features

The NCAT plans were designed to reduce the cost of the conservation features by making them easier to install. For example, the construction sequence itself is designed to reduce cost. The outer wall is built in a conventional fashion to serve as a bearing wall.

Raised heel or "energy trusses" that accommodate more ceiling insulation are installed and the roof is finished.

Triple-glazed windows or double-glazed windows with a special low emissivity or "low-e" film are installed, along with insulated doors with high-quality weatherstripping. To take advantage of passive solar heat, more window area is installed on the south side of the building.

With the windows and doors in place, the builder has a large open loft, out of the weather, to complete the second non-bearing stud wall to accommodate the extra wall insulation. The open loft allows for easy application of the air-vapor barrier, which is installed continuously and carefully sealed to cut air leaks through walls, floor and ceilings.

In order to ensure that a high degree of tightness is achieved, a blower door device is used to de-pressurize the house so that any air leaks can be detected and sealed. In the Montana project, all the houses were very tight on the first blower door test, and the test allowed them to further tighten the building envelope. Another test a year later showed that no significant degradation of the seal occurred.

The Ventilation System

The NCAT plan calls for a central ventilation system that uses a "heat recovery ventilator," or HRV, to recover heat. This heat recovery device is an air-to-air heat exchanger, which is a simple device that mechanically pulls stale warm air from the house and transfers the heat to the fresh air supply being brought into the house. Heat exchangers do not produce heat, they only recover the heat by exchanging it to the other air stream. The process works to some degree in reverse in the summer.

This heat transfer takes place in the core of the heat exchanger, which is typically made up of thin sheets of plastic or metal, and is designed to avoid mixing of the two air streams.

The builders and possible buyers in the Montana project learned how new this technology is for residential application. The original residential model pioneered less than a decade ago by the Canadians in their research house was made of plywood and household plastic for the core!

In the last few years, the new technology has developed rapidly. Due to stimulation by programs in Canada, Minnesota and the Northwest, the industry has rapidly changed and models keep improving. In the United States, the industry is moving to implement performance standards to help guarantee performance for consumers, and BPA and the Northwest state energy offices can provide guidance as to acceptable models and installation practice for houses using the technology in these states.

The desire for wintertime comfort and low heat bills has led to considerably tighter construction practices in the last few years, but the need for ventilation is often overlooked. Most people are used to "passive" ventilation through cracks and leaks in the building shell, and they do not understand the need for continuous ventilation in the wintertime.

Unfortunately, the newness of the technologies and the lack of understanding has often meant that ventilation is ignored in tightly built superinsulated houses.

In addition to ventilation instruction, builders in the Montana project were given advice on selecting materials and products that don't contain problem chemicals. Builders were taught to ventilate the house well during the construction phase to remove pollution that is a part of the construction process, such as fumes from paint and varnished surfaces.

By reducing all sources of pollution from the building materials, and by providing controlled, continuous ventilation, the superinsulated house can offer a wide degree of occupant control over the indoor environment. The ventilation system runs at a low, continuous rate during the heating season, and the occupant can increase the ventilation rate whenever it is desired.

The heat exchanger used in the project was the Van EE R-200, made in Canada. When the manufacturer released a newer model, the R-2000, NCAT asked them to donate the newer model so that the study of the ventilation system could reflect the latest advances in the hardware.

The NCAT plans call for a pressure plenum to distribute fresh air to all areas of the house. Unlike a forced air heating system that moves heated air at a high velocity, this type of ventilation system has a low-speed, continuous flow of

air that is introduced at the ceiling level to provide for good air mixing.

Air is continually pulled from the kitchen, bath and laundry areas and exhausted through the heat exchanger.

The Heating System

The Montana project homes are all electric, so that they may be compared with all-electric homes built under the BPA program. The heating system used electric resistance baseboard, with a thermostat in every room. This allowed a great degree of occupant control over each room of the house, while reducing the first cost of the system.

Natural gas or other combustion heating systems can be used in superinsulated houses, but the builder must be cautious to avoid a clash of technologies - combustion appliances have not been thoroughly researched for application in extremely tight houses. As a part of the Montana project, NCAT produced a publication for DNRC on cautions and recommendations related to using combustion appliances in tight houses.

Water Heating

The Montana project also required builders to install high-efficiency water heaters. These heaters are conventional

tank-style heaters that have much more insulation in the tank, as well as valves that keep hot water from being wasted through convection into the water lines. A survey of available models showed that these types of water heaters can be purchased at the same cost as more conventional models. Due to distance from suppliers, some builders spent more.

Based on studies performed by BPA on the most cost-effective conservation improvements to electric hot water systems, NCAT recommended several additional low-cost measures as well to ensure the best performance possible. Because most tank water heaters have no insulation on the bottom, a "bottom board" of tough foam insulation was installed under the tank. This stops the substantial heat loss that can occur when the tank sits on a cold basement floor. In addition, a conventional R-11 tank blanket was added to the outside of the tank, and the hot water pipes were insulated for the first four feet of the hot water line coming from the tank. The best way to describe the water heaters is superinsulated.

THE RESEARCH PROGRAM

How all these elements performed in the Montana project houses requires a closer look at more than simple consumption at the power meter. In a conventional house, there is no way to break down where the energy is going. In the BPA demonstration

project, electric meters were used to break down space heat, hot water, and total consumption.

By contrast, the monitoring system for the study of the Montana project uses a low-cost portable lap computer that collects hourly data from seventeen measurements. Each week data is collected through a computer that calls each house and in minutes transports the information to the project analyst. The data is scanned for errors and archived.

The continuous data collected from these houses is detailed, and includes:

*Five indoor temperatures

*Power consumed by:

- Upstairs heat
- Downstairs heat
- Water heater
- Dryer
- Whole house

*Solar radiation on the south wall

*Outdoor temperature

*Gallons of hot water used

*Temperatures of supply and exhaust air through the heat exchanger

*Fan operation on both fans in the heat exchanger

This level of study takes the guesswork out of why and how

the houses perform as they do, and gives researchers enough detail to more clearly define the performance of the houses. With more simplistic measurements, it isn't possible to say whether space heat was being supplied by the sun or by the appliances. And without sufficient indoor temperature measurements, it isn't possible to track whether the space heat cost what it did because the occupant didn't heat a room, or because a room was kept at 80 degrees.

In addition to these measurements, spot measurements and other studies were conducted from time to time. These included measuring how much air was being delivered by the HRV, and whether the air streams were in balance. An appliance audit was conducted to confirm the measurements, since individual power outlets were not measured. And, surveys of occupants were conducted two times during the project - in early 1985 and in mid-1986 to better understand the measured data, and to gauge occupant reaction to the houses.

Measured Results

The energy features of the Montana project must be put in the context of the houses themselves and the people who live in them. The performance of the houses reflect the diversity of the participants, as well as the energy design.

The occupants and the researchers both learned the impact of

the lifestyle choices of the people on their individual energy bills. With nearly identical houses from an energy standpoint, the occupant patterns taught both groups a great deal.

The three Great Falls sites were occupied from the beginning of the monitoring period, while the site in Lewistown was occupied only part of the first full year of monitoring. The Billings site was unoccupied during the entire year, but it was heated during the 1985-86 season to serve as a control house for the occupied houses.

Total Energy Consumption

Of the total annual electric bill, the measurements showed this average breakdown for the first full year of measurements from the occupied houses:

Space heat	- 26 percent
Water heat	- 17 percent
Dryer	- 4 percent
All other	- 53 percent

For an electrically heated house in Montana, the value of 26 percent for space heat is very low. The results for the water heaters were also very good, and compare well with the predicted

results from the BPA studies. The dryer consumption is small compared with the others. The water heater and the dryer do not contribute to space heat, which is why they were individually measured. For the most part, all other electric uses reflected in the 53 percent contribute to space heat.

The level of "other" electricity uses is rather high in this group of houses. These extra electricity users - lights, kitchen appliances, hand-held appliances, electronic equipment, water beds, extra freezers, and the hot tub - are a reflection of lifestyle, but they also consume a fair amount of electricity as well as contribute to space heat.

Clearly the choice of appliances such as refrigerators and water heaters has a large impact on what the consumer will pay when the utility bill arrives. The term "energy efficient" is often used inaccurately, and builders and consumers should be encouraged to practice careful shopping habits. While the energy guide labels are helpful, consumers are often not aware of the range of choice they have, and how a few extra dollars spent at first can save hundreds in the first year.

Ranges of Operating Costs

Before construction, computer models were used to predict the space heat performance of the houses. These predictions were for heating the full house including the basement to 65

degrees. At 1983 prices, this translated into an annual cost of $226, (or roughly $113 to heat the upper floor alone). With current rates it would translate to $356.

In practice across the sites, each occupant family heated the house to their own comfort. This ranged from keeping bedrooms quite cool to keeping the living room at 72 degrees. Table I shows the ranges of operating costs for space heat, hot water, dryer and other uses at a rate of 5 cents per kilowatt hour.

This information reflects the diversity of the occupants. Family size ranged from two persons to four persons. But, their preferences and habits determined the final bill.

TABLEI: RANGES OF MEASURED ANNUAL OPERATING COSTS:*

(at $.05/kWh)

	LOW	HIGH
SPACE HEAT	$193	$337
HOT WATER	$108	$244
DRYER	$ 15	$ 61
"OTHER"	$422	$584

*(OVER THREE OCCUPIED SITES IN GREAT FALLS, MT.)

The research has indicated that space heat cost is closely tied to temperature setting, with each degree of increase making for a five percent increase in space heating cost. One family kept the house uniformly heated to an average of about 71 degrees throughout the house, and this family had the highest bill. The family had moved from a drafty mobile home and preferred warmer temperatures and uniform heating.

Another family preferred to keep some rooms cooler, with others warmer, with temperatures ranging from 62 to 71 degrees. One occupant family manually set thermostats, calling for more heat when needed. All these behaviors strongly affected total space heat costs.

The hot water consumption reflects how many gallons were used. This amount is usually closely tied to the number of occupants in the house.

Strategies to recapture waste heat from clothes dryers look less attractive when one sees how little electricity dryers can consume. NCAT recommends against ducting dryers to the indoors because of indoor air quality and humidity problems that can result.

The "other" category is the major electricity consumer in this project. The house with the hot tub used the most, but some households had rarely used appliances that consumed energy at all times. Because in most households the space heat and hot water consume the vast majority of the energy used, people are not sensitive to the amount of energy used by appliances. But,

additional savings are possible through attention to this area in the future.

Another illustration of this point is Table I that shows the breakdown of the estimated inputs to space heat among the three houses in Great Falls. The appliance energy contributed an estimated 53 percent to the space heat requirement, a number that was possible to derive partly due to the unoccupied control house. If more efficient appliances were used, some of this energy might have been supplied by the sun.

The differences between the occupants' energy use was far greater than any slight thermal differences in the construction of the houses. Thus, it is not possible to say whether one type of window performed better than another, for example, or whether having slightly more glass on the south side would have made any major impact on energy performance.

Occupant Reaction

Superinsulated houses are very quiet - the extra insulation and tightness keeps noise outside. This allowed one builder to locate next to a busy freeway, without suffering from the noise. Another family had lived in the country and grown accustomed to the quiet. When they first moved into town, they found it difficult to adjust to the city noise, but after moving into their new superinsulated house the quiet of the country returned.

Most occupants took a few months to adjust to the new house - the quiet, the wintertime comfort, the new approach to ventilation and the fact that lights, appliances and the sun provide so much of the heat.

This new aspect took two of the families by surprise, and the houses overheated at times during the first winter until the occupants made adjustments. One family reported that they reduced thermostat settings and kept some rooms intentionally cooler; they opened the doors to these rooms when the sun, appliances or visitors added extra heat. Another family chose to open windows to get rid of undesirable heat.

Another noticeable behavior was the lack of attention paid to the solar features of the house. Most of the occupants reported that they didn't take action to maximize solar gain, such as opening window coverings regularly on the south side during daytime sun. Another family didn't shade south windows, even when temperatures rose to a high level in the living areas. They said the extra warmth was generally desirable, and simply opened windows if it got much too warm. In general, the occupants seemed to prefer to ignore the solar features, and make no adjustments to regular routines related to the new house.

As internal heat gains became better understood, the occupants found themselves adjusting nicely to the new houses.

The first summer in the houses was a mild one, with measured outdoor temperatures staying below 90 degrees in Great Falls.

Air conditioning is not traditionally installed in new houses in Montana, due to the short summer season which is usually mild. The 1986 summer was much warmer than the previous summer, and, due to heat from sources like the refrigerator and stoves, most occupants reported that they had a bit of an adjustment period to the very warm weather. Several families reported that they used traditional strategies to stay comfortable, such as opening windows at night, and closing them and shading windows by daytime. (The houses are designed with a roof overhang to shade the south-facing windows in summer, but west windows may need shading through window coverings.)

Several occupants used the ventilation system in the daytime to cool down incoming air. The ventilation system's intake is on the north side of the house, where temperatures are lower. One family commented that rooms on the north side of the house always stayed cool enough, and that little action was needed to keep the house comfortable. All occupant families generally reported that the energy features of the house helped in the summertime, as well. One occupant suggested that an air conditioner would be a nice addition to the ventilation system, but none of the occupants reported the need for air conditioning through two summer seasons, nor did any purchase air conditioners.

All-Electric Heating

None of the occupants had ever lived in an all-electric home before, with all being accustomed to gas forced-air heating, and one having used wood heat before. Asked for their reaction to the electric systems, most said they liked the ability to have rooms at different temperatures, something that wasn't easy with central forced air heating. Another noted that the forced air system seemed to add to wintertime dryness in the former residence. (In conventional houses that are ventilated through cracks and leaks, forced air heating systems do increase the ventilation rate. In winter, this can mean that more cold air is drawn into the house and when warmed, becomes very dry.)

All occupants rated the houses as very comfortable, winter and summer. And, all said they would choose such a house again, with the exception of a renter family, who said that they strongly valued a fireplace in a new house.

LIVING WITH AN HRV

For most occupants, the biggest change from what they were used to in previous houses was the heat recovery ventilation (HRV) systems.

The level of understanding of the new technology was a key factor in how fast the occupant family adjusted to the HRV. At

the beginning of the occupancy period, the families had different levels of education about the HRV. The owner-builder had adequately installed the system, but didn't have much of an idea about what it was meant to do. Another occupant had a high level of understanding, after taking part in educational seminars offered by NCAT.

Learning About Defrosting

The experience with the first winter of the Montana project mirrored occupant experiences in Canada for the two previous seasons. The HRV in use the first winter was an efficient, reliable machine, but it required manual defrosting during very cold weather, and began icing at about 10 degrees. On a practical level, this brought ventilation to a virtual halt during the coldest weather. Windows would begin fogging, and the occupant would need to go to the basement, slip a duct off the machine and run basement air through the machine until the ice block was melted, an operation that took about 20 minutes. The occupant didn't need to wait at the machine - the machine was in essence recirculating basement air throughout the house. But to remove indoor humidity and unfog the windows, the duct needed to be slipped back onto the machine, which would then run about 24 hours before needing another defrost.

One occupant followed this regime without any prompting, simply by reading the manual that came with the machine. Another occupant needed to be shown how to do this. A third reported that the family liked the excess humidity, and didn't defrost the machine manually. Instead, they turned the machine off, letting the ice melt more slowly.

While defrosting the machine is another household chore, like sweeping snow from the walks in winter, it is something that occupants quickly adjusted to as a action that was needed during very cold weather. Defrosting the HRV wasn't difficult, and the occupants didn't complain of it or find it objectionable. Of course, reaction to this depends on the temperment of the occupant.

Defrosting Improvements

The Canadians had gone through this for two seasons, and the manufacturer of the Van EE introduced a device known as a "frostbuster," which through a motorized damper, automatically recirculated basement air through the machine to keep the unit operating full time through the coldest weather, eliminating the need for manual defrosting of the machine.

To keep up with changes in the technology, NCAT asked the manufacturer to donate its newest model to the project, and these machines were installed in all five sites in January 1986.

The new machines provided greater air delivery and better overall ventilation, but are slightly less energy efficient because they don't ice up and stop altogether in cold weather. The greater air flows also reduce heat transfer to the incoming air stream to some extent, making for slightly cooler incoming air temperatures to the living space.

The occupants noticed the change, and two out of four didn't like it much, saying they thought the house was being over-ventilated. One occupant said he preferred the older unit, defrosting and all! NCAT is providing adjustments to the machines to provide occupant satisfaction, through reducing the air flows, before the 1986-87 winter season.

What this experience illustrates is the newness of the technology, and the fact that manufacturers are struggling to match machine capabilities with the way the ductwork systems are installed. In some houses, a large amount of ductwork reduces air flows to the point where a more powerful HRV will be needed to provide adequate ventilation. In the NCAT houses, with the use of a pressure plenum and good design, air resistance through the ductwork is minimized, and a more powerful HRV may bring on occupant discomfort.

It should be noted that two of four families didn't mind the change in the machines, which points out that people's tastes and preferences for ventilation are probably as variable as their choice of temperature settings in different rooms.

NCAT's recommendation has been that these new systems should provide the greatest degree of occupant control possible, and that the low speed, continuous ventilation setting should be comfortable for occupants.

Getting Used to The Change

New technologies are often mysterious, and one of the project families turned the machine off from time to time during the first winter. The HRV seemed to make this occupant nervous. The machine didn't make noise or otherwise seem to be obtrusive, but the occupant felt more comfortable turning it off. As the occupant grew accustomed to the new technology, however, the data showed that the system began to run full time.

In housing programs in the United States and Canada where installation of the HRV has been less than optimal, a wide variety of problems have been noted. Where ductwork and the air delivery system was poorly designed, air flows have been reduced below recommended levels. In addition, the balance of incoming and outgoing air can be poor due to bad ductwork design. Vibration noise can also be a problem in poor installations. And, when ducts were installed similar to forced air heating systems with fresh supply air coming in at the floor level, the cooler air has caused occupant discomfort. The best advice is to introduce this air high on the wall, similar to a commercial

air conditioning approach.

With the exception of complaints of "over-ventilation," the Montana project HRV systems have operated satisfactorily. And, occupants have reported a variety of benefits from having a controlled ventilation system. (Surveys of occupants in Canada have shown that despite the problems, the overwhelming majority would choose an HRV again.)

For example, the humidity level can be controlled by adjustments in the ventilation system. In Montana, most people complain of wintertime dryness, and many find it necessary to humidify the air for some part of the winter. With a controlled ventilation system, however, occupants can have a steady rate of humidity that is well above what is typical during very cold weather.

Controlled continuous ventilation is much more effective at quickly removing indoor air pollution than random ventilation through air leakage. This is a real asset when people are visiting, during parties, or when smoking is occurring in the house. During an open house at one of the sites in Winter 1985, people coming into the house were asked if they thought smoking had been going on in the house. All reported that no smoking had been going on in the house, when a short time before, a number of people had been smoking nearby.

Another benefit of a controlled ventilation system is that incoming air can be filtered. High quality filters are

available that can help reduce allergy reactions to pollen and other irritants.

Perhaps the greatest benefit is the fact that with an HRV system, a house can be built very tightly, thus reducing cold drafts that are a prime wintertime complaint in Montana and other cold-climate regions. And, with a properly designed and installed system, ventilation is a known commodity, not something that changes with wind speed, direction or outdoor temperature.

Lack of HRV Service

Yet, the service structure for the new technology is sketchy. Few firms offer design services, and few firms know how to properly install the systems. Work pioneered in Canada is slowly being transferred to the Northwest and Montana, and training programs are being offered that are helping to spur along the technology. But consumers wanting to use it today had best seek substantial information and be prepared to know what to ask for, and what to expect.

Builders who want to use the technology should seek extra training, and follow the best advice available. In addition, occupants should be given solid, basic information about all aspects of operating the system.

The systems require about the same level of maintenance as

is recommended by forced air heating manufacturers. Filters need to be cleaned every few months, and parts need occasional oiling. Part of superinsulation's future technology may include the annual "house tightness and ventilation system check." This service would include doing a pressurization test to identify air leaks, and a check of the ventilation system. Businesses are starting to offer this unique service in a few areas of the United States, and it may well be a part of the home maintenance package of the future.

SUPERINSULATION ECONOMICS

The energy performance of the Montana Superinsulation Project houses was highly dependent on occupant behavior. Also, the cost of the houses themselves varied a great deal, depending on builder and buyer choices unrelated to the energy features.

Before the construction season, NCAT had estimated that the cost of building from this houseplan with a finished basement was about $54,000, excluding land costs, floor coverings, refrigerator and contractor's overhead and profit. The plan shows low-cost siding, and moderate cost kitchen cabinetry. Of this cost, a total of about $4,500 represents the extra cost of insulation, air-vapor barrier and ventilation system over current standards of construction.

Reports from the builders indicated that land costs ranged from about $8,000 to $15,000 per site. Choice of higher quality kitchen cabinets and other interior finishes substantially increased this cost for some builders. And, exterior finish improvements would also increase the base cost, in some cases substantially. In total the sale price of the homes ranged from about $70,000 to $83,000, including land.

Due to the BPA's emphasis on determining the "extra" cost of energy features in Model Conservation Standards demonstration homes, builders were asked to complete a "cost data manual," at construction time that would show how much extra the energy features of the home cost that particular builder.

NCAT asked the builders in the Montana project to fill out the same cost data manual. One experienced builder said filling out the manual wasn't worth the time: from past experience he said there was no extra cost for the energy features compared with previous similar homes he had built in the area. In his judgment, the cost savings of the NCAT house plan were borne out. A second builder was too far along to accurately complete the manual. In the owner-builder's case, the manual couldn't be accurately completed. This left a first-time contractor and an experienced solar builder. The first-time contractor showed extra costs for the energy features that exceeded the NCAT estimates by about $3,000, a result that may be due to lack of previous accounting experience. The experienced builder's cost

data manual was within $400 of the NCAT estimate.

One of the main features of the NCAT houseplan is the cost-saving design and construction sequence, and the fact that the plan saves the builder substantial calculation and on site planning time. One goal of the plan effort was to reduce construction costs to cover the "extra" costs of the energy features.

As the project construction season progressed, it was clear that a builder's choice of lot or exterior siding could add more cost than the energy features. Floor covering choices and kitchen cabinetry options could also substantially increase house costs. Clearly, houses are not sold on energy efficiency alone; while it is of growing importance to many buyers, it is only one of the many possible features of a new house. And it may be the least visible of the options on the surface. But unlike the other features, the energy features are expected to provide a dollar return or pay for themselves in direct energy savings.

As the houses were finished and occupied, it became obvious that the energy features of the Montana houses were performing as predicted. Compared with a similar-sized all-electric home built to current practice, the occupants might have saved roughly $600-$1,000 in the first year on electric space heat and water heat (based on estimates advertised by a Montana utility in a promotion for natural gas). But how can these homes be

compared with similar houses that use other fuels, different insulation levels and heating systems? Without further study, it continues to be an "apples and oranges" type of comparison. Less costly fuels have been successfully used in superinsulated houses, but more field research is necessary to define the real needs and best economic and comfort approach to this puzzle.

Current methods for calculating the economic benefits of the superinsulated house do not assign a dollar value to the extra comfort, noise reduction or controlled ventilation and air quality features of this type of construction. To date, only the energy savings are put into the economic equation.

Clearly, more study is necessary to better define consumer benefits of superinsulation, and put them into context with other taste-and-preference choices that people make in the new-home market. To date, the most easily defined benefit other than energy savings is that with lower operating costs offered by energy-efficient housing, a homebuyer might better qualify for a mortgage or qualify for a larger mortgage. In other words, energy efficiency might help homebuyers on the margin of qualifying to buy a new house, or it might enable the homebuyer to afford a larger mortgage to buy a better appointed house. Either way, it seems like an obviously wise investment from a consumer standpoint.

Summary of Educational and Outreach Programs

Throughout the Montana project, NCAT has worked to provide information and details from the research to those who need it. Through media stories, TV interviews and other means, the project team worked to provide useable information.

In January and February 1985, NCAT conducted public open house information sessions at four of the sites, with more than 1,000 people attending. Simultaneous builder trainings in the three project cities attracted more than 100 professionals.

A direct mail campaign reached more than 1,000 other professionals.

And for researchers and specialists working to provide quality, low-energy housing, NCAT produced a conference in May 1985 to provide an information and education exchange about all the work in energy efficiency in buildings going on in Montana, the Pacific Northwest and Canada.

To provide this information rapidly and to encourage regional and international communication, NCAT produced a 450-page pre-published proceedings to help make new data and studies known to those who need it in Montana, the Northwest and the rest of the nation. To encourage working relationships with those studying the new methods and companies developing new products suitable for energy efficient housing, NCAT also produced a product exhibition to accompany the Montana conference.

In addition, ten technical papers, covering all aspects of the project, have been delivered by the project team in Montana, Alaska, Minnesota and other major conferences or meetings.

CONCLUSIONS

The Montana Superinsulation Project holds lessons for all its intended audiences. But, no single effort can overcome the remaining hurdles to energy-efficient construction or reduced electricity consumption. The impact of using a detailed plan that was based on substantial research should not be underemphasized when one reviews the results of this project. The plan allowed builders of various experience levels to build houses that performed very similarly; the differences between occupants grossly outweighed any differences between the houses in the sample.

The plans also reduced the time and trouble (and associated costs) of building with these new energy features, and in particular the ventilation system. It is clear that more easy-to-understand technology transfer tools are needed to assist those who want to use these methods.

In general, more work is needed before these new housing methods become a common practice. In order to compare the value provided by the new technologies, we must examine such areas as indoor air quality, ventilation, and the relationship between

appliance use and space heat. Some of these areas will be undergoing study during the next year.

Montana and the Northwest are pioneering a number of new technologies and methods that promise to provide comfort, value and low operating costs in the housing of the future. For those innovative builders and buyers who want the future today, a growing number of information and education tools are becoming available. But these tools need to be backed up with hard data, not guesswork. Information, education and research programs like the Montana Superinsulation Project play an important role in this effort.

RESOURCES AND SOURCES OF INFORMATION

BOOKS

The following books provide information on various aspects of superinsulation technology:

Energy Efficient Home Construction: Basic Superinsulation Techniques [A Superinsulation Training Manual], Bob Corbett and Barbara Miller, National Center for Appropriate Technology, PO Box 3838, Butte, MT 59702.

"Installers Manual For Heat Recovery Ventilators," Heating, Refrigerating, and Air Conditioning Institute of Canada, Islington, Ontario, Canada 1985.

Installing Residential Air-to-Air Heat Exchangers, Richard Karg and Richard D. McGinley, Jr., Portland Energy Group, PO Box 8245, Portland, ME 04103.

Major Energy Conservation Retrofits: A Planning Guide for Northern Climates, Fred Quivik and Brian Shovers, National Appropriate Technology Assistance Service, PO Box 2525, Butte, MT 59702.

Sun/Earth Buffering and Superinsulation: Building for Energy Independence, Don Booth with Jonathan Booth and Peg Boyles, Community Builders, Canterbury, NY 03224.

The Superinsulation Home Book, J.D. Ned Nisson and Gautam Dutt, John Wiley & Sons, Inc., 605 3rd Ave., New York, NY 10158.

The Superinsulated Retrofit Book: A Homeowner's Guide To Energy-Efficient Renovation, Brian Marshall and Robert Argue, Renewable Energy in Canada, 107 Amelia St., Toronto, Ontario, Canada M4X 1E5.

PERIODICALS

The following periodicals frequently publish the latest information on developments in superinsulation technology:

Energy Design Update, Cahners Publishing Co., PO Box 716, Back Bay Annex, Boston, MA 02117.

Habitat 2000, Third Wave Communications, Inc., PO Box 4885, Edmonton, Alberta, Canada T6E 5G7.

Practical Homeowner, Rodale Press, Inc., 33 E. Minor St., Emmaus, PA 18049.

Progressive Builder, SolarVision, Inc., 7 Church Hill, Harrisville, NH 03450.

Solplan Review, Drawing Room graphic Services, LTD., Box 86627, North Vancouver, B.C., Canada V7L 4L2.

TECHNICAL PAPERS

The following technical papers relating to the Montana Superinsulation Project have been published as of October, 1986.

"Instrumentation Using Personal Computers," Charless W. Fowlkes and Al Beldring, Fowlkes Engineering, 31 Gardner Park Drive, Bozeman, MT. Published in the Proceedings of Conservation in Buildings: Northwest Perspective, a conference organized and co-sponsored by NCAT as part of the Montana Superinsulation Project in Butte, Montana, May 19-22, 1985.

"Measured Thermal Performance of Three Superinsulated Houses in Montana," L. Palmiter and J. Hanford, Ecotope, Inc., Seattle. Published in the Proceedings of Conservation in Buildings: Northwest Perspective, NCAT, May 1985.

"Measured Thermal Performance of Three Superinsulated Homes in Montana,: Second Report," L. Palmiter and J. Hanford, Ecotope, Inc., Seattle. 11th National Passive Solar Conference, Boulder, CO June 1986.

"Occupant Reaction to Low-Energy Housing," Barbara A. Miller and Robert J. Corbett. Published in the Proceedings of Conservation in Buildings: Northwest Perspective, NCAT, May 1985.

"Preliminary Performance Assessment of Three Ventilation Systems Employing Air-to-Air Heat Exchangers," R. Corbett, B. Miller and D. Hagan. Published in the Proceedings of Conservation in Buildings: Northwest Perspective, NCAT, May 1985.

"Public Research and Technology transfer: The Challenge," B. Miller and R. Corbett. Published in the Proceedings of Conservation in Buildings: Northwest Perspective, NCAT, May 1985.

"Quantifying Infiltration in Five Houses in Eastern Montana," T. Benson, B. Miller, R. Corbett. Published in the Proceedings of Conservation in Buildings: Northwest Perspective, NCAT, May 1985.

"The Montana Superinsulation Project: A Preliminary Report," by B. Miller and R. Corbett. Prepared and presented at the Third Annual National Conference on Superinsulation in Housing, Rochester, Minnesota. April 1985.

"The Montana Superinsulation Project: A Public Research Effort," by Corbett and Miller. Prepared and presented at the 6th Annual Alaska Alternative Energy Conference, Anchorage, Alaska. March 1985

"Thermal Components of the Montana Superinsulation Project Houses: Energy, Construction Techniques and Cost," R. Corbett and B. Miller. Published in the Proceedings of Conservation in Buildings: Northwest Perspective, NCAT, May 1985.

ORGANIZATIONS

For more information on energy efficient housing and related programs in Montana contact DNRC:

Montana Department of Natural Resources and Conservation
Energy Division
Capitol Station
Helena, MT 59601
406/444-6696

For more information on superinsulation, or the Montana Superinsulation Project, as well as for information on other alternative energy and appropriate technologies, contact NCAT:

National Center for Appropriate Technology
P.O. Box 3838
Butte, Montana 59702
406/494-4572

For assistance regarding your problems and questions relating to conservation, building technology, solar, wind, hydro, and other alternative energies and appropriate technologies, contact NATAS:

National Appropriate Technology Assistance Service
(NATAS)
P.O. Box 2525
Butte, Montana 50702
Toll Free In Montana: 1-800-428-1718
Toll Free elsewhere: 1-800-428-2525

SUPERINSULATION CLOSE-UP:
RESULTS FROM THE MONTANA SUPERINSULATION PROJECT THERMAL MEASUREMENT EFFORT
December, 1984 – September 1986

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SUPERINSULATION CLOSEUP:

RESULTS FROM THE MONTANA SUPERINSULATION PROJECT

THERMAL MEASUREMENT EFFORT

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REFERENCES

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I. INTRODUCTION

Superinsulation is a group of building methods that was born on the cold plains of Saskatchewan in 1977-78. In response to the rapid rise in energy costs and the extremely cold winters, the Canadians built a demonstration and research house that was the first attempt at building an extremely tight building shell and replacing ventilation through cracks and leaks with a controlled, heat recovery ventilation system. The house also featured much greater insulation levels from basement to attic.

These features allowed passive solar gains to be more effective, and allowed windows of conventional size to be used, rather than the larger windows required when insulation and infiltration levels were more typical.

It was clear that the methods could be adapted to a wide range of architectural styles, and that even without southern orientation, the heating costs would be lower than with any other approach tried up to this point. The magnitude of the drop in space heating energy demonstrated by the Saskatchewan Conservation House was the biggest news of all. In 1977-78 dollars, the Canadians reported a space heating cost of less than $40 for the first year.

These results stimulated great interest in both Canada and the United States. By the next winter, more than 60 houses were built in Canada that attempted to repeat the spectacular performance of the first house. At NCAT, the Passive Solar Group changed orientation and began analysis to verify that conservation was more cost-effective than passive or active solar alone. A simulation model was developed, and optimization techniques were used to provide more definition and guidance related to the most cost-effective approaches to employing higher insulation levels.

The NCAT Building Technology Group worked to translate these results into a set of highly detailed drawings for a low-cost house for low-income occupants. This houseplan was the first attempt to integrate the new controlled ventilation approach into the architecture of the house. The air-to-air heat exchanger for residential application was not yet developed sufficiently to specify at the time of this work. The two groups planned to build the house at the NCAT headquarters to verify the projections and analysis used to develop the plan. But funding for such research came to a complete halt in this timeframe, and the groups disbanded to continue the work at other locations.

Builders across the Northern Tier continued to try to employ the methods and technologies. And the Canadians quickly developed the R-2000 program, which was designed to assist builders through training, computer simulation design assistance

and financial support. In Minnesota, the state and other groups co-sponsored an incentive program to build 144 houses that employed passive solar or attempted to use superinsulation. This work was first reported on in 1982.

In 1982, California proposed residential energy conservation standards that included the new methods of superinsulation for the colder northern climate regions.

In 1983, the Northwest Power Planning Council, representing the public in Washington, Oregon, Idaho and Montana, developed a power plan for the Pacific Northwest that included Model Conservation Standards for new residences that included superinsulation methods as an option to meet the performance requirements.

While policy makers, builders and governments were all anxious to promote superinsulation as a hope for stimulating energy conservation in the residential sector, painfully little applications research was being done to support large-scale adoption of the methods. The particularly weak link was the newness of the approach of building an extremely tight building shell and employing a controlled ventilation system. In addition, much of the information about superinsulation was being developed in the field by builders, who were anxious to try a wide variety of methods to achieve the higher insulation levels and the tight building shell.

Several new publications sprang up in this timeframe to report the action, and one was particularly vocal in reporting how many superinsulated houses had been built in the U.S. Given the state of the art with the ventilation systems, however, it is clear that few houses were employing the whole package developed in Canada - it was simply too difficult to employ an uncharted technology, and NCAT received many reports in the 1982-83 timeframe of builders and owner-builders who made little or no attempt to install a ventilation system in their tightly built homes.

At Lawrence Berkeley Laboratory, a data base was set up to collect information about energy efficient new houses. The data base contained information about earth-sheltered, passive solar and superinsulated houses. Some research reports on this information stated that, based on available information, superinsulated houses were the best performers from a cost and performance standpoint. However, these case studies were not easily comparable.

In 1982, NCAT surveyed these events and networked with the Canadians and those doing research. Two former members of the NCAT building technology group had produced two more versions of the detailed houseplan, and the plans were offered to interested people. By 1983, roughly 1,000 sets of plans had been

distributed. A survey in 1983 by NCAT showed that a majority of the plans were used for educational tools to assist builders, owner-builders and researchers to understand the methods. NCAT considered the notion of attempting to get performance information from those who had built from the plans, but it was clear that little scientific information could be obtained through this avenue.

In 1983, the Bonneville Power Administration announced the Residential Standards Demonstration Program (RSDP), under which hundreds of new homes would be built throughout the Pacific Northwest to gain information on the cost of the Model Conservation Standards proposed by the Power Council. In addition, low-level energy monitoring with power meters was planned.

In 1983, NCAT proposed to the Montana DNRC, that houses built from the NCAT houseplans be built and more extensively measured for thermal performance in Eastern Montana, which was outside the BPA service territory for the RSDP program. In addition, NCAT proposed information and education efforts for Eastern Montana for interested buyers and builders, aimed at providing conservative information that would alert these groups to the need for ventilation and to avoid problems reported elsewhere related to attempts to combine tightness with conventional combustion appliances.

The goals of the research efforts were amplified by the pressing need for more detailed, verified and reliable field data on the performance characteristics of superinsulation, "characteristics" that had seemingly become fact through four years of field work by innovative builders in situations where no verification or field research was possible. For example, it was held as fact by many that superinsulated houses could be heated with a single point source of heat. Magazines trumpeted the 64-cent annual heating bill.

While much hoopla and promotion was going on for the new methods, NCAT found that little research was being done to support the many claims, and it was clear that an engineering field study would greatly add to our knowledge and understanding of the methods and practices. Moreover, the study would help shed light on what information should and could be recommended to those in Montana who want to safely employ the new technologies and practices.

Another goal of the research was to validate the developmental research assumptions and performance predictions that were the basis for thermal design features of the detailed houseplan developed in the 1978-80 timeframe. A third goal was to provide data of such detail that the simulation model could be better refined and validated against the real-world data of

this project. Such simulation models are important tools to allow projections of possible energy savings, as well as clarify the effect of design changes and other aspects of value to policy makers, code writers, designers and builders.

This research was to be done in a public setting, and the goal was to provide results rapidly. The work represented an on-going step in the project group's continued study and development of the methods and practices known as superinsulation. But, not all the needed research could be addressed under funding limitations of this project. The measurements taken did not have a high level of detail on the air-to-air heat exchangers or the basements. These remain to be studied this winter season. In addition, support for the in-depth study of this concise data has been difficult to find. Indications are that many findings are awaiting this deeper level look at the data.

This report describes measurements and studies accomplished to date on this case study. New methodologies were developed in some cases, and the project team strove to apply resources in a manner consistent with the goals of appropriate technology, which call for a wholistic examination of technological options to resource allocation problems. The project team continues to solicit interest and support for study of the many remaining questions.

The cost of the research aspects of this project, including donated labor and time by the project team, are equivalent to about three of the modestly priced project houses in the Montana sample. Hundreds of houses are built in Montana each year, and many thousands more are built across the Northern Tier. Technological change cannot occur overnight, but through continued study and education, a growing fraction of these new houses may be built with features that provide occupant comfort and satisfaction as well as value and energy efficiency. And investments in these houses pave the way for a well-planned energy future. However, investments in our knowledge and understanding of new methods must come first.

II. ABSTRACT

Five all-electric superinsulated houses were built from an experimental houseplan in Eastern Montana in 1984. The houseplan was developed at the National Center for Appropriate Technology in 1982, and updated in 1984-5.

The houses were instrumented with remote data acquisition systems that have collected more than a year's worth of continuous hourly data on seventeen channels, starting in late December 1984. The houses have had several types of one-time testing including three blower door tests, flow measurements on the air-to-air heat exchangers, and appliance audits. Occupant surveys were completed at two points during the measurement period.

Three sites have been continuously occupied, one has had periodic occupancy, and one has been unoccupied throughout the measurement period. The unoccupied house has served as a control.

The homes are virtually identical houses - ranch-style houses with 1,288 square feet of space on the main floor, and similarly sized full basements, for a total square footage of roughly 2,400 square feet. Each house has zoned electric baseboard heating units with separate thermostats in each room. Extra insulation and other measures were installed on high-efficiency tank domestic hot water heaters.

Energy performance has been consistent with predictions, and is summarized as follows:

1) Space heat consumption varies by two to one in the occupied units, due to different thermostat settings, and different levels of internal and solar gains.

2) Average annual 1985 space heat consumption for the three occupied homes in Great Falls was 5,207 kilowatt hours, (2.17 kWh/sqft) with 8,218 base 65 degree days. The occupied home in Lewistown performed similarly, while the control home in Billings (unoccupied) used roughly 2,277 more kilowatt hours, reflecting the loss of internal gains from occupancy.

3) Average annual 1985 total electric consumption in the occupied houses in Great Falls was 20,077 kWh, of which 26 percent was space heat, 17 percent was water heat, 4 percent was dryer and 53 percent was "other," which includes everything else.

III. DESCRIPTION OF THE HOUSES AND MEASUREMENTS TAKEN

A. Description of the Houses

1. The Houseplans

The NCAT houseplan effort captured three years of study in passive solar and energy conservation, including test cells, computer model development and economic analysis of construction techniques. In addition, an overriding goal was to reduce the overall cost of construction to cover the marginal costs of the conservation features.

The plan in use in the Montana project was an updated version of the NCAT plan 2 known simply as "Plan 2.1." (The designers have produced four types of houses in this form: Plan 1, a small, low-cost version; Plan 1M, a modular version of the small house; Plan 2, a larger ranch-style with full basement, and a "designer" version, known as The Timberloft.)

An analysis of cost versus R-value for 27 wall sections led to the conclusion that a double-stud wall appeared to have the best combination of cost, availability of materials and the least break with standard practice.

The plans are unique in that they show the installation sequence of the air-vapor barrier, show highly detailed schematic, Plan, elevation, and isometric drawings of the controlled ventilation system, and in general have a level of detail that makes these changes, as well as the double-wall construction method, easily understood to both experienced builders and owner-builders.

2. Thermal Elements of the Houseplan 2.1

The plan in use in the Montana project is a version very similar to Plan 2, except for minor changes to ductwork design of the ventilation system and the rim joist vapor barrier detail. As it turned out, two houses in the sample (Sites 2 and 3) used the older version, while three others used the new updated version.

Thermal elements of the plan include:

INSULATION LEVELS:

* R-50 in the ceiling
* R-40 double stud walls on east, west and north
* R-26 single, 2X6 wall, with exterior rigid insulation on the south wall
* 35.7 sqft of glazing on the south wall; 13.8 sqft of glazing on each of the west east and north walls
* R-3 glazing on all windows (either triple glazed or low-E glazing)
* R-12 metal-clad doors
* R-8 under entire basement slab
* R-19 on interior basement walls

HEATING AND VENTILATION

* 16 feet of electric resistance baseboard in basement; 19feet of electric resistance baseboard on main floor; thermostats in all rooms

* Mechanical ventilation using Van EE R-200 (1985) and Van EE R-2000 (1986) air-to-air heat exchanger; pressure plenum fresh air distribution systems for both basement and main floor, with exhaust air returns in kitchen, laundry and all baths

Other objectives related to the performance of the houses in the Montana project included:

* Continuous polyethylene air-vapor barrier installed under the sheetrock and sealed with acoustic sealant to achieve a measurement of 1 air change an hour (ach) or less at 50 pascals pressure in a blower door test.

* High performance electric domestic water heater with R-16 to R-20 in-tank insulation; 3-inch rigid bottom board insulation under tank; anti-thermosiphoning valves; hot water pipe insulation on first four feet; and R-11 exterior tank wrap.

III. THE HOUSES AS BUILT

The project started with five volunteer builders. These builders received Plan 2.1 and two days of instruction in July 1984. Two of these builders left the program in October 1984 due to sluggish housing markets. Two other houses under construction using the older Plan 2 joined the program in November 1984, and these builders were given no training program. All builders had decided to build with eight-foot ceilings (instead of the 7'6" ceilings shown in the plans) and to attempt to use a similar window type and keep location according to the plans. However, due to the late entry of the new houses, and due to needed changes by builders, some minor thermal changes occurred under construction. They are summarized below:

* Sites 1 and 5 vary to some degree from true south
* Site 3 is raised higher in relation to grade, and is bermed on the east, west and north sides.
* Sites 4 and 5 have attached garages
* Some window area variations and type variations were recorded; low-e glazing is used almost exclusively on the original project houses at sites 1, 4, and 5, while the "late entry" houses at Sites 2 and 3 use a mix of low-e, conventional double glazing and triple glazing. (See Table 1: Size and Orientation of Net Glazing Areas, and Table 2: Relationship of South Net Glazing Area to Total Glazing and To Floor Area.)

TABLE 1: SIZE AND ORIENTATION OF NET GLAZING AREAS
(in square feet)

SITE	1	2	3	4	5	HOUSE PLAN 2.1
Main Floor						
North	11.21	0	14.32	16.67	22.04	13.8
South	39.95	54.80	58.19	36.69	39.03	35.7
East	11.21	14.32	14.32	0	11.02	13.8
West	11.21	14.32	14.32	11.12	0	13.8
Subtotal	73.58	83.44	101.15	64.42	72.09	77.1
Basement						
North	0	0	0	5.51	5.51	0
South	7.77	7.16	14.32	5.48	2.74	7.6
East	0	0	0	0	5.51	0
West	2.16	7.16	0	0	0	7.6
Subtotal	9.93	14.32	14.32	10.99	13.76	15.2
GRAND TOTAL	83.51	97.76	115.47	75.41	85.85	92.3

TABLE 2:
RELATIONSHIP OF SOUTH NET GLAZING AREA TO TOTAL GLAZING AND TO FLOOR AREA

SITE	1	2	3	4	5	HOUSE PLAN 2.1
TOTAL SOUTH GLAZING (sq.ft.)*						
	47.72	61.96	72.51	42.17	41.77	43.3
TOTAL NON-SOUTH GLAZING (sq.ft.)*						
	35.79	35.80	42.96	33.24	44.08	49.0
SOUTH GLAZING AS PERCENTAGE OF TOTAL GLAZING **						
	54.3%	65.7%	57.5%	57.0%	54.1%	43.3%
SOUTH GLAZING AS PERCENTAGE OF MAIN FLOOR AREA**						
	3.3%	4.6%	4.9%	3.1%	3.3%	3.4%

*Includes both main floor and basement glazing area.

**Includes main floor glazing area only.

Graphic presentations of the floor plans and elevations for the as-built sites are shown as Appendix A: Floor Plans and Elevations of the Montana Superinsulation Project Homes.

IV. DESCRIPTION OF CONTINUOUS MEASUREMENTS

Continuous measurements are taken on the following:

Total (kWh)
Upstairs heat (kWh)
Downstairs heat (kWh)
Clothes dryer (kWh)
Hot water heater (kWh)
Water heater flow (gal/day)
Solar radiation (BTU/sqft)
Ambient temperature (on north wall) (F)
Fan status on both fans on the air-to-air heat exchanger (on/off)
Temperature on both incoming and outgoing air stream of the heat exchangers (F)
Temperature sensors in main living area, three upstairs bedrooms, and one in the basement, for a total of five indoor temperatures. (F)

For details on the instrumentation see Appendix B: Instrumentation Using Low-Cost Computers.

Data was collected weekly beginning in December 1984 at Sites 1, 2, and 3. Start-up at Site 4 was in January, 1985, with Site 5 coming on line in February, 1985. Data losses through the period were minimal, with the exception of a lightning-caused breakdown at Site 2 in summer 1985, that caused a loss of several weeks of data. Funding for data collection and archiving ended April 30, 1986. The measurement systems were maintained through this writing, given funding limitations, and are being prepared and checked for another season of measurement starting November 1986.

V. ONE-TIME MEASUREMENTS AND STUDIES

A) Fan Pressurization Tests

Pressurization/ depressurization tests were made on the five sites at three times. At each site, the same sequence of procedures were followed.

The first test was a diagnostic test, while the second was taken when the house was ready for occupancy. The third round was done in April 1986. The purpose of the first test was to point out any air leakage that builders might want to seal. The

second test was to see what the final results were and establish a base line. The third test was to see whether the air leakage rate had increased over the period of one year.

The door in use is a Minneapolis Blower Door that uses nozzles calibrated to ± 5 percent. Barometric pressures, relative humidity and wind speed were measured. Tests were thrown out if wind speed exceeded 12 miles per hour.

B) Appliance Audits

In order to better understand the breakdown of "other" uses, which were not separately measured with the exception of the clothes dryer, appliance audits were conducted at all five sites. The audits were performed in March 1985 on Sites 1, 2, and 3, and in September 1986 on Sites 4 and 5.

The audit methodology and rationale is described in Appendix C: Appliance and Light Energy Audits for the Montana Superinsulation Project.

C) Occupant Surveys

In order to clarify the measured data and get a better understanding of the occupants' role in operating the houses, occupant surveys were performed in March 1985, and August 1986.

Sites 1, 2 and 3 had been continously occupied by the same families throughout the measurement period, while Site 4 was rented by two families, with periods of unoccupied time. Site 5 was unoccupied until March 1986. New renters occupied the house beginning in May 1986, but disconnected the measurement system upon their arrival.

The surveys included roughly 25 questions and a general interview. Many of the questions were not applicable to the new families or the renter families, who had not been in the houses long enough to be able to answer. However, through interview techniques, each occupant family's tastes and preferences were catalogued, and reaction and interaction with the energy features of the houses were noted.

D) Air flow measurements on the Heat Recovery Ventilator (HRV)

At the beginning of this project, a simple, reliable measurement technique for accurately gauging air flows through the heat exchanger had not been developed. In order to get a rough idea of what was occurring in this regard, a series of measurements were made in the early part of 1985, using hot wire anemometers and prototypical measurement gear that employs a magnehelic gauge. A wide range of measurement results were the outcome, but it was possible to roughly check the balance of the air flows, and see a band of likely air flow measurements for each HRV system. All engineers and specialists connected with

this effort noted that the level of confidence in the measurements was not high, and that wind gusts and other measurement problems made taking an accurate measurement difficult.

In January 1986, NCAT installed new HRV's, and flow grids were installed in the exhaust and supply ducts. These grids allow a rapid measurement with a magnehelic gauge. Since that time, a series of measurements made from the flow grids have been taken.

A more detailed description of the HRV systems is found in Appendix D: Preliminary Performance Assessment of Three Ventilation Systems Employing Air-to-Air Heat Exchangers.

VI. SUMMARY OF RESULTS

A) Results of Continuous Measurements

Early in the measurement period, it became clear that the occupants' behavior was a major factor in the performance of the houses. In particular, space heat consumption varied by 2 to 1 between the occupied sites. In addition, these sites varied due to differences in internal gains and solar gains. The pattern of Site 4's performance when occupied is very similar, despite the fact that it is located more than 100 miles from the Great Falls sites. Site 5 was a useful control house, when this unoccupied site was heated during the 85-85.

The first three months of occupied data is summarized in Appendix E: Measured Performance of Three Superinsulated Homes in Montana. This report contains a number of graphic representations of the data, which are useful in understanding the performance of the homes during this period.

Highlights of these early findings included:

1) The first winter of occupancy saw higher levels of basement space heat than first floor space heat. This data may have recorded the effect of the basement soil being charged and warmed during the first season.
2) Space heat consumption corresponded well with measured degree days.
3) Occupant preference for indoor temperatures ranged from roughly 65 degrees to 74 on average, depending on the room and the site.
4) Based on this preliminary data, the houses were performing close to predictions made in advance with SUNDAY, a daily simulation model, and with earlier, modified CALPAS 3 predictions.
5) Hot water consumption and energy use was consistent with expectations, and standby loss analysis showed low values, ranging from .45 to 1.38 kWh/day.

Analysis performed a year later with all available data bore out predictions made in the preliminary data analysis. But, the occupants continued to explore and change their preferences related to temperature and other choices, compared to the first winter season.

The first whole winter season data on the four occupied sites indicated:

1) The houses generally have a four-month heating season - November through February. Average measured space heat consumption at the four occupied sites during these months was 4,253 kWh, with the unoccupied control site using 7,202 kWh, reflecting the lack of internal gains. Measured heating degree days (base 65) during the four months ranged from 4,639 to 4,900 across the sites. Average indoor temperatures ranged from 66 to 73 in the main living area. Specific values for all sites is shown as Table 3.

TABLE 3: DATA SUMMARIES FOR ALL SITES, NOVEMBER 1985 THROUGH FEBRUARY 1986

ELECTRICITY CONSUMPTION (kWh)	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
UPSTAIRS HEAT	1385	1584	2211	3104	3533
BASEMENT HEAT	1606	2825	2751	1548	3669
TOTAL HEAT	2991	4409	4962	4652	7202
DRYER	499	103	294	671	0
WATER	1633	710	1912	1441	17
OTHER	4344	3158	3898	1975	492
TOTAL APPLIANCE	6467	3971	6104	4087	509
HOUSE TOTAL	9467	8380	11066	8739	7711
TEMPERATURES (F)					
BEDROOM 1	65.6	68.1	72.2	69.5	66.6
BEDROOM 2	65.5	70.0	71.1	68.1	67.0
BEDROOM 3	68.1	70.8	71.7	68.6	68.2
DINING ROOM	66.7	72.5	73.3	67.3	68.0
BASEMENT	66.3	71.9	70.0	60.7	66.2
AVERAGE HOUSE	66.5	70.7	71.7	66.8	67.2
AMBIENT	25.9	24.7	25.8	24.2	26.3
AVERAGE DELTA	40.6	46.0	45.9	42.6	40.9
HOT WATER (GAL/DAY)	57.0	34.6	71.2	49.0	.3
VERTICAL SOLAR (BTU/SQFT/DAY)	926	871	963	942	781
HEATING DEGREE DAYS (F-DAY)	4693	4835	4701	4900	4639

2) Of the average space heat consumption in the first full year of measurements, about 5,200 kWh was the average for space heat across the occupied sites.

3) Site 4 occupants turned down thermostats in the basement, keeping the basement at a cool average temperature of 60 degrees. They used substantially more kWh in upstairs space heat than the other three sites. However, the final consumption total was only 400 kWh more than the average between the sites. These occupants used less for "other" uses as well, experiencing considerably less internal gains.

For the first year's summer season, the data clearly showed the effect of the roof overhang, with the south windows completely shaded from direct radiation from May through mid-August. During the warmest weather, the houses generally ran at similar or lower than outdoor measured temperatures.

These effects are more clearly seen in plots contained in Appendix F: Measured Performance of Superinsulated Homes In Montana: Second Report.

SUNDAY runs were performed early in the measurement period, with the input parameters of the January 1985 space heat use averaged across the three Great Falls homes. These inputs were:

Thermostat Set Point	65	F
Building UA	263	
Heat Storage	6,000	
Internal Gains	4,500	
South Glass	54.8	
North Glass	8.8	
East Glass	14.3	
West Glass	23.1	
Shade Factor	.7	

Use of actual weather data with the same assumptions yielded a predicted annual space heat consumption of 5,253 kWh, which was within 0.8 percent of the actual measured average result. The predictions were also in agreement with the unoccupied control home. This does not imply that the parameters are correct, however.

The simulations provided this estimate of the contribution of various heat sources toward the overall thermal load:

Heating System	5,253 kWh	34 percent
Passive Solar	1,991 kWh	13 percent
Internal Gains	7,999 kWh	53 percent

Another estimate from SUNDAY was that for Great Falls, the space heat load would increase to 12,080 kWh and the solar to 21

percent if no internal gains were present. About 42 percent of a reduction in annual internal gains will appear as an increase in annual space heat consumption.

The analyst noted the difficulty of making predictions for space heat for specific months or for individual sites: the occupants' use of multiple thermostats making for large room-to-room temperature variations is a major factor. In addition, vacations, changes in internal and solar gains and other effects also make this type of prediction difficult.

Annual summaries for Sites 1 through 3 are shown as Table 4.

B. Appliance and Light Audits

Of the Montana sample, three of five houses have a fairly large consumption in categories other than space heat. This consumption makes up 74 percent of the total consumption on average between the three continuously occupied sites.

Of this energy, two points - the water heater and clothes dryer - are continuously measured, and consumption is reported in the tables above. The average of all other appliance and light consumption is still 10,569 kWh/year, a sum that is considerably larger than that found in other studies.

Appliance and light audits were conducted at all five sites to gain a better understanding of what this energy is purchasing for the occupants.

The measured data shows a strong seasonal variation in "other" use at Sites 1 and 2, with Site 3's "other" use staying fairly constant. Sites 4 and 5 were audited at a different time because they were not occupied at the time of the audits at the other sites.

The audits represent a snapshot of other energy uses that helps further explain the measured data. The audit results and estimations were within 15 percent of consumption measured continuously.

Other electricity consumption choices are broken down into the following categories, which represents the typical inventory items by catagory.

Refrigeration	Refrigerator-Freezer Freezer
Food Preparation	Range Oven and Cook Top Microwave

TABLE 4: 1985 ANNUAL DATA SUMMARIES FOR THE MONTANA SUPERINSULATION PROJECT

	SITE 1		SITE 2		SITE 3		AVERAGE OF SITES 1,2,&3	
ELECTRICITY CONSUMPTION (kWh)								
UPSTAIRS HEAT	1579	8%	2289	15%	2770	11%	2246	11%
BASEMENT HEAT	2279	11%	2639	17%	3965	16%	2961	15%
TOTAL HEAT	3858	19%	5028	32%	6735	28%	5207	26%
DRYER	1226	6%	308	2%	903	4%	812	4%
WATER	3436	17%	2150	13%	4882	20%	3489	17%
OTHER	11576	58%	8441	53%	11689	48%	10569	53%
TOTAL APPLIANCE	16238	81%	10899	68%	17474	72%	14870	74%
HOUSE TOTAL	20096	100%	15927	100%	24209	100%	20077	100%
HOT WATER (GAL/DAY)	41.7		37.5		76.1		51.8	
VERTICAL SOLAR (BTU/SQFT/DAY)	936		994		943		958	
HEATING DEGREE DAYS (F-DAY)	8101		8435		8117		8218	
SPACE HEATING								
KWH/SQFT	1.61		2.10		2.81		2.17	
BTU/SQFT-DEGREE DAY	.68		.85		1.18		.90	

Food Preparation	Coffee Maker
	Slow Cooker (crock pot)
	Electric Fry Pan
	Toaster
	Can Opener
	Blender
	Popcorn Maker
Lighting	Table/Floor Lamps
	Built-in Lamps
	Night Lights
Air Quality	HRV Ventilation Fans
	Range Hoods
	Air Purifier
	Humidifier
Entertainment	Television
	Video Recorders/Player
	Stereo and Accessories
	Radios
	Hot Tub
Housekeeping	Clothes Washer
	Clothes Dryer
	Dishwasher
	Vacuum Cleaner
	Trash Compactor
	Garbage Disposal
Other	Waterbed Heater
	Electric Blanket
	Clocks
	Battery Chargers
	Personal Hygiene Products
	Mechanical Tools
	Lawn Tools

Across the five occupied sites, the estimated energy end-use by category is shown in Table 5.

C. Occupant Surveys

Family size across the five sites was two to four. Occupants had a number of similar responses to interview questions:

1) None had lived in an all-electric home before, with all being used to gas forced air primarily (with wood in one case) as the only space heating type before living in the new home.

2) All rated the home as very comfortable.

3) All owners said they would choose a similar superinsulated home again.

TABLE 5: ESTIMATED ENERGY BY END USE CATEGORY (kWh/mo)
(Clothes Dryer Not Included)

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
REFRIGERATION	121	169	410	154	240
FOOD PREPARATION	92	170	232	89	67
LIGHTING	259	64	183	52	93
AIR QUALITY	180	180	160	0	74
ENTERTAINMENT	245	46	61	31	22
HOUSEKEEPING	23	29	64	19	37
OTHER	38	123	61	48	17
TOTAL	958	781	1171	393	550
ESTIMATE ACCURACY	-15%	+6%	+10%	NA	NA
MONTH	MAR	MAR	MAR	SEP	SEP

In the occupied homes in Great Falls, the families took a few months to adjust to the solar gains and internal gains, and overheating during the winter was reported at two of three sites. At Site 2, this led to reduced thermostat settings, while Site 3 chose to open windows if overheating occurred. No overheating was reported during the second winter season.

Another noticeable behavior was the general lack of attention paid to the solar features of the house. Based on responses related to the use of window coverings, it is apparent that little extra attention was paid to maximizing solar gain.

In summer, several occupants used the ventilation system as part of their cooling strategy; others used windows for ventilation completely.

One renter family reported difficulty in adjusting to the new house, and in particular, the ventilation system. This family was the only family that said they would not choose a similar superinsulated house again, saying they preferred having a fireplace. However, they said they liked the "weathertightness" of the home.

Occupants in brief:

Site 1: Three occupants (One adult in 20's, two children under 10); children at home on some days; occupancy is intermittent at other times.

Site 2: Two occupants (retired couple); home occupied almost all the time.

Site 3: Four occupants (Working couple in 30's, two children under age 10); home occupied only on nights and weekends.

Site 4: Renter family number 2 (Previous family not surveyed.) Four occupants, (Two adults in 30's, two children under 10); home occupied nearly all the time.

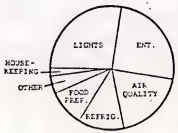
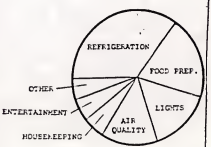
Site 5: Renter family number 2 (Previous family not surveyed.) Three occupants, (Two adults in 30's, one infant); home occupied nearly all the time.

Information related to measured performance, occupant characteristics and energy choices from the appliance audit are shown as Figure 1.

VII. AIRTIGHTNESS RESULTS

The three tables below summarize results of the three blower door tests. Tests were taken in two modes: one with the house in an as-is condition, another with all penetrations such as

FIG : ANNUAL SUMMARY, OCCUPANT PROFILES AND END US AKDOWN ESTIMATE BY AUDIT -- OCCUPIED SITES

	SITE 1		SITE 2		SITE 3	
ELECTRICITY CONSUMPTION (kWh)						
UPSTAIRS HEAT	1579	8%	2289	15%	2770	11%
BASEMENT HEAT	2279	11%	2639	17%	3965	16%
TOTAL HEAT	3856	19%	5028	32%	6735	28%
DRYER	1226	6%	308	2%	903	4%
WATER	3436	17%	2150	13%	4882	20%
OTHER	11576	58%	8441	53%	11689	48%
TOTAL APPLIANCE	16238	81%	10899	68%	17474	72%
HOUSE TOTAL	20096	100%	15927	100%	24209	100%
HOT WATER (GAL/DAY)	41.7		37.5		76.1	
VERTICAL SOLAR (BTU/SQFT/DAY)	936		994		943	
HEATING DEGREE DAYS (F-DAY)	6101		8435		8117	
SPACE HEATING						
KWH/SQFT	1.61		2.10		2.81	
BTU/SQFT-DEGREE DAY	.68		.85		1.18	
OCCUPANT PROFILES:						
This information describes the occupant characteristics for the three sites in Great Falls for which the data was collected.	Three occupants One adult, mid 20's Two children, under 10. Rarely home during day		Two occupants Two adults, retired Home most of the time		Four occupants Two adults, in 30's Two children, under 10 Home evenings, weekends	
END USE BREAKDOWN BY SITE						
Appliance and light audits in March 1985 show breakdowns of kilowatt hour consumption by end-use category, excluding dryer and water heater. The area for each end-use is proportional to the amount used. Consumption of "other" electricity varies from month to month, and seasonally; these represent March 1985 only. They do illustrate the differences in occupant tastes and preferences for electricity use in this sample.					

ventilation, plumbing and dryer vent sealed. Values are shown in air changes per hour at 50 pascals pressure. Measurements were converted to other values using the models developed at Lawrence Berkeley Laboratories and in Canada. These values are shown as Appendix G: Fan Pressure Test Results By Site.

Measured results of the diagnostic and turnkey tests as well as a comparison of results with the third round of testing are shown in Figure 2.

In general, the houses showed insignificant change over the year between the turnkey test and the one administered in April 1986, with the exception of Site 3, where this owner-builder added an addition to the house. The specialist administering the test speculated that the addition, as well as other changes in the basement, led to the increase in ach at this site.

VIII. RESULTS OF AIR FLOW MEASUREMENTS AND OTHER STUDIES

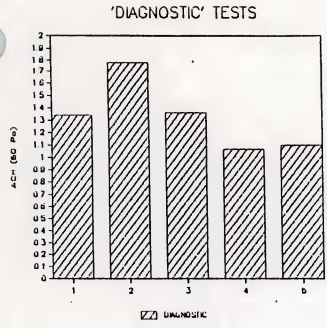
During the first winter, the Van EE R-200 was in use in the project houses. Three sites - 1, 4, 5 had similar ductwork configurations, as they were built from the revised project plan. Builders at Sites 2 and 3 did not take part in the NCAT training programs, and the ductwork configurations both varied substantially from the revised project plan. In the case of Site 2, extra duct elbows and other changes led to substantially increased resistance. At Site 3, the builder brought supply air from the south side of the house, and exhausted air to the north side.

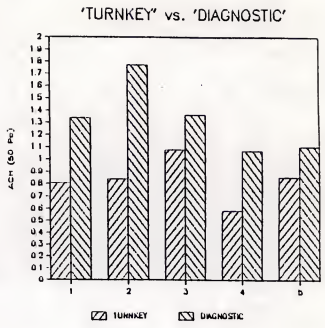
Air flow measurements taken in the first winter, as described earlier, showed substantially less air flows at Sites 2 and 3 than at the other three sites. These values and qualifications are shown with later measurements in Appendix H: Air Flow Measurements from the Montana Superinsulation Project.

Calculations on the early measurements found that continous air supply at low speed fan operation would supply from .2 to .3 ach across the sites, and that high speed operation would supply from .25 to .5 ach depending on the site. It should be noted that these were crude estimates based on the best measurements that could be obtained, and the project team had questionable confidence in the measurements, but the ranges were noted.

Performance characteristics that were noted from the continuous measurements included:

1) The machines performed very similarly across the sites in regard to temperatures and defrost operation.





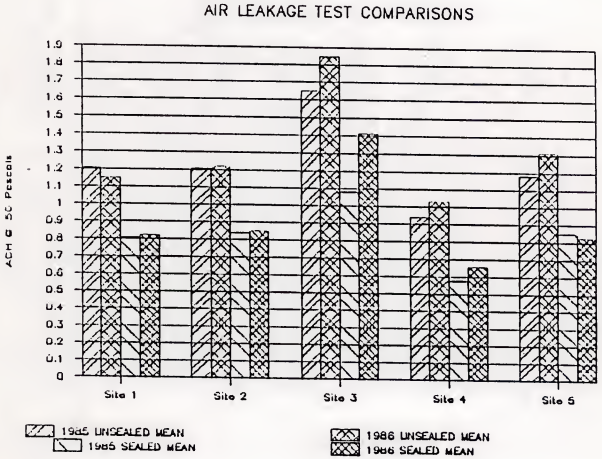


FIGURE 2: RESULTS OF DIAGNOSTIC, TURNKEY AND COMPARISON OF 1985 AND 1986 TESTS

2) Defrost mode (supply fan off ending ventilation) occurred at about 0 degrees F, and that icing appeared to begin affecting performance at outdoor air temperatures of 20 degrees F. Manual defrost was necessary to resume ventilation during prolonged cold snaps (below 0 F.)

In January 1986, the Van EE R-2000 was installed at all five sites, and ductwork was modified. This resulted in similar air flow measurements across the five sites. As noted in the report in Appendix H, the change to the new machine increased measured air flows substantially, and the difference from low speed to high speed was substantially reduced. Mechanical ventilation increased to roughly .4 to .5 ach with the new systems.

Two occupant families found this level of ventilation to be too much, and looked for ways through changing the controls to reduce the ventilation rate. Both began turning off the machines at times.

By switching fan motors at all five sites and altering the voltage on the motors on the fans, ventilation at two sites was altered to provide approximately .375 ach at low speed and .5 ach at high speed.

Little continuous measured data during very cold weather was available except for a small period in February. The defrost mode altered substantially with the new unit, with defrost lasting an average of only a few minutes each time. In essence, the machine runs virtually all the time, thus making for less efficiency than the older unit, which would go off entirely until it was manually defrosted during the coldest weather.

For the 1986-87 winter season, a detailed study including extra measurements on the heat exchangers is planned. These will include continuous flow and relative humidity measurements. The settings at the beginning of this experiment will be aimed at reducing the low-speed operation mode to provide about .3 ach, with high speed in the .45 to .5 range.

IX. ECONOMIC NOTES

As has been shown, the total energy performance of the Montana Superinsulation Project houses was highly dependent on occupant behavior. And, the cost of the houses themselves varied a great deal, depending on builder and buyer choices unrelated to the energy features.

Prior to the construction season, NCAT had estimated that the cost of building this houseplan was about $54,000, excluding land costs, floor coverings, refrigerator and contractors overhead and profit. The plan shows low cost siding, and moderate cost kitchen cabinetry. Of this cost, a total of about $4,500 represents the extra cost of insulation, air-vapor barrier and ventilation system over current standards of construction.

X. CONCLUSIONS

The results of this thermal measurement effort must remain in the context of the detailed NCAT houseplan, that allowed five builders with a wide range of prior experience to build houses that perform similarly. The occupant differences overwhelm any thermal differences, from an analysis standpoint.

It is possible that thermal performance may be able to be improved over these results in future designs, but for this type of housing, the next frontier is clearly the optional electricity use represented in the "other" category by this measurement effort.

Another conclusion from the study is that low-cost thermostats don't allow a superinsulated house with passive solar features to be controlled easily by the occupant. Thermostat error was noted to be substantial in early verification checks, and occupants had difficulty finding their best comfort regime for the first several months in the houses. Overheating and substantial temperature swings were measured. Savings could be achieved and comfort enhanced if thermostats were sensitive to the cycles of this type of house. Even with occupant education about the impact of internal and solar gains, most people are not prepared for the reality of it, and inaccurate thermostats make the adjustment more troublesome.

The relationship of internal gains to space heat load has been estimated using a simulation model. The homebuying public and policy makers have focused most of the effort on the reduction in space heat energy consumption, but little attention is paid to the rest of the utility bill. Without extra metering, builders employing superinsulation techniques are unable to show consumers the impact of the "other" energy uses, and consumers don't have any means by which to separate end uses to confirm that thermal performance has been delivered. In addition, many consumers don't have important information about choices in the "other" category, and they don't have any feedback on where their energy dollars are going.

In the new technology of HRVs, substantial growth and change occurred during the course of this project. The Canadian R-2000 program has spurred a rapid development in the technology, which is finding favor for cold-climate use. But, the service networks to provide for adequate design, installation and maintenance of HRVs do not yet exist in the U.S. as they are beginning to in Canada. Those using the technology are still pioneers, despite the growth and improvement in the last three years.

Measurements Not Taken

No indoor air quality measurements were taken on these houses during the first measurement period. In order to begin a year-long look at radon levels, radon badges were installed at all

Reports from the builders indicated that land costs ranged from $8,000 to $15,000 per site. Choice of higher quality kitchen cabinets and other interior finishes substantially increased this cost for some builders. And, exterior finish improvements would also increase the base cost, in some cases substantially. In total the sale price of the homes ranged from about $70,000 to $83,000, including land.

Due to the BPA's emphasis on determining the "extra" cost of energy features in Model Conservation Standards demonstration homes, builders were asked to complete a "cost data manual," at construction time that would show how much extra the energy features of the home ran that particular builder.

NCAT asked the project builders in the Montana project to fill out the same cost data manual. One experienced builder said filling out the manual wasn't worth the time: from past experience he said there was no extra cost for the energy features compared with previous similar homes he had built in the area. In his judgment, cost savings of the NCAT houseplan were borne out. A second builder was too far along to accurately complete the manual. In the owner-builder's case, the manual couldn't be accurately completed. This left a first-time contractor and an experienced solar builder. The first-time contractor showed extra costs for the energy features that exceeded the NCAT estimates by about $3,000, a result that was probably due to lack of accounting experience. The experienced builder's cost data manual was within $400 of the NCAT estimate.

One of the main features of the NCAT houseplan is the cost-saving design and construction sequence, and the savings realized by the builder in research and "head scratching" time. One goal of the plan effort was to reduce construction costs to cover the "extra" costs of the energy features.

As the project construction season progressed, it was clear that a builder's choice of lot or exterior siding could add more cost than the energy features. Floor covering choices and kitchen cabinetry options could also substantially increase house costs. Clearly, houses are not sold on energy efficiency alone; while it is of growing importance to many buyers, it is only one of the many possible features of a new house. And, it may be the least visible of the options on the surface. But, unlike the other features, the energy features are expected to provide a dollar return or pay for themselves in direct energy savings.

As the houses were finished and occupied, it became obvious that the energy features of the Montana houses were performing as predicted. Compared with a similar-sized all-electric home built to current practice, the occupants might have saved roughly $600-$1000 in the first year on electric space heat and

water heat (based on estimates advertised by a Montana utility in a promotion for natural gas). But, how can these homes be compared with similar houses that use other fuels, different insulation levels and heating systems? Without further study, it continues to be an "apples and oranges" type of comparison. Less costly fuels have been successfully used in superinsulated houses, but more field research is necessary to define the real needs and best economic and comfort approach to this puzzle.

Current approaches to calculating the economic benefits of the superinsulated house do not assign a dollar value to the extra comfort, noise reduction or controlled ventilation and air quality features of this type of construction. To date, only the energy savings are put into the economic equation.

Clearly, more study is necessary to better define consumer benefits of superinsulation, and put them into context with other taste-and-preference choices that people make in the new-home market. To date, the most easily defined benefit other than energy savings is that with lower operating costs offered by energy-efficient housing, a homebuyer might better qualify for a mortgage or qualify for a larger mortgage. In other words, energy-efficiency might help homebuyers on the margin of qualifying to buy a new house, or it might enable the homebuyer to afford a larger mortgage to buy a better appointed house. Either way, it seems like an obviously wise investment from a consumer standpoint.

While consumers tend to want the lowest possible space heating and hot water costs, they may be expecting to spend $2,500 or more on a heating plant for a new house. In the Montana project, the heating and ventilation systems together cost about $2,000 installed according to a builder's report. But, consumers are not accustomed to buying "ventilation" equipment, only heating equipment. They are not used to buying equipment to provide what before had no upfront cost - passive ventilation through cracks and leaks. Unfortunately, the annual space heating cost of crack and leak ventilation is not well defined in new construction, due to a lack of studies. Nor has the adequacy of the passive ventilation approach been studied in detail. Of course, the future is bringing the obvious combination of heat recovery
ventilation and space heating, and new products engineered for the residential market are being further developed. Field engineered combinations by builders and others have been reported.

But, the consumer's best value still must be explored. The economic equation must take into account the cost of the heating and hot water equipment, as well as the cost reduce heat lossed through the building envelope.

X. CONCLUSIONS

The results of this thermal measurement effort must remain in the context of the detailed NCAT houseplan, that allowed five builders with a wide range of prior experience to build houses that perform similarly. The occupant differences overwhelm any thermal differences, from an analysis standpoint.

It is possible that thermal performance may be able to be improved over these results in future designs, but for this type of housing, the next frontier is clearly the optional electricity use represented in the "other" catagory by this measurement effort.

Another conclusion from the study is that low-cost thermostats don't allow a superinsulated house with passive solar features to be controlled easily by the occupant. Thermostat error was noted to be substantial in early verification checks, and occupants had difficulty finding their best comfort regime for the first several months in the houses. Overheating and substantial temperature swings were measured. Savings could be achieved and comfort enhanced if thermostats were sensitive to the cycles of this type of house. Even with occupant education about the impact of internal and solar gains, most people are not prepared for the reality of it, and inaccurate thermostats make the adjustment more troublesome.

The relationship of internal gains to space heat load has been estimated using a simulation model. The homebuying public and policy makers have focused most of the effort on the reduction in space heat energy consumption, but little attention is paid to the rest of the utility bill. Without extra metering, builders employing superinsulation techniques are unable to show consumers the impact of the "other" energy uses, and consumers don't have any means by which to separate end uses to confirm that thermal performance has been delivered. In addition, many consumers don't have important information about choices in the "other" catagory, and they don't have any feedback on where their energy dollars are going.

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Measurements Not Taken

No indoor air quality measurements were taken on these houses during the first measurement period. In order to begin a year-long look at radon levels, radon badges were installed at all

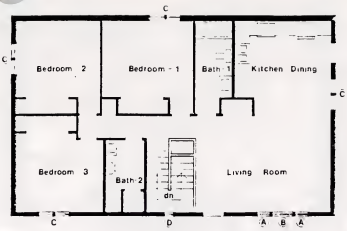
five sites in July 1986. A much more substantial indoor air quality study would be indicated on houses where much is known already, but whether this will be possible is unclear at this writing.

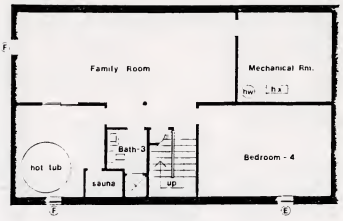
The analyst has frequently noted the need for more basement temperatures in order to better define the thermal performance of the basements. It is not possible to further clarify the thermal model of the houses without more basement measurements. The project team is hoping to find support for such study. Very little data exists on heat losses from basements, in particular, well-insulated basements.

In a search for comparable data, NCAT found that no long-term research of a HRV in the field had yet been accomplished in this country. Policy and standards groups are currently drafting performance specifications for ventilation systems, but little hard data is available, nor are companion ventilation studies in hand to provide necessary guidance for design of these systems. Research is planned this winter on the Montana Superinsulation Project sample, and similar work is in progress under the auspices of the Ontario Research Foundation. In total, four makes of HRV will be studied at this level. For the Montana project, this will involve the addition of 18 channels of continuous measurement, several donated to the basement study area.

APPENDIX A:

FLOOR PLANS AND ELEVATIONS OF THE MONTANA SUPERINSULATION PROJECT HOMES





GLAZING AREA (FT^2)	
SYMBOL	AREA
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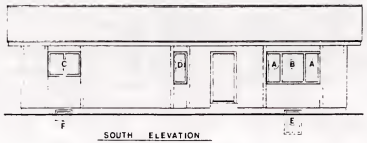
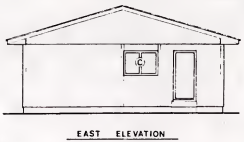
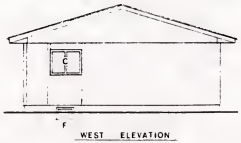
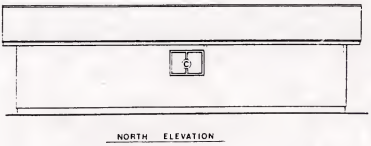
B	11.45
C	11.21
D	4.90
E	5.61
F	2.16









SITE 1

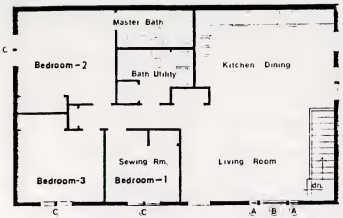
NORTH

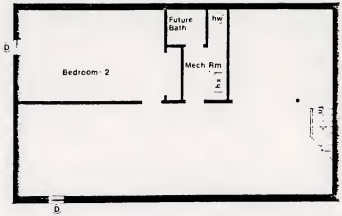
0 5 10

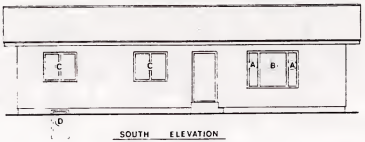
SCALE

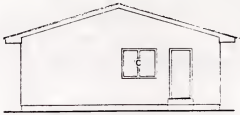
E-27

FIGURE 4: FLOOR PLANS AND ELEVATIONS - SITE 1 (GREAT FALLS: 7598 DEGREE DAYS)









GLAZING AREA (FT^2)	
SYMBOL	AREA
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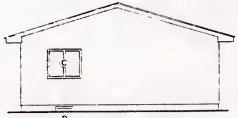
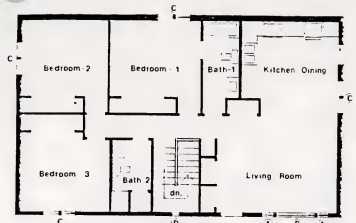
B	16.63
C	14.32
D	7.16

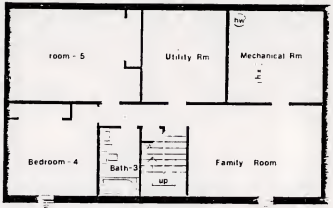


E-28

FIGURE 5: FLOOR PLANS AND ELEVATIONS - SITE 2 (GREAT FALLS: 7598 DEGREE DAYS)

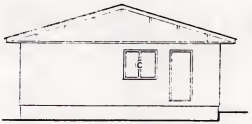


FIRST FLOOR PLAN



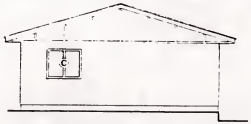
BASEMENT PLAN

SOUTH ELEVATION

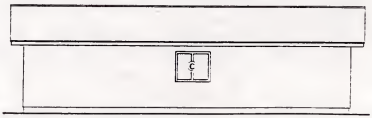


EAST ELEVATION

GLAZING AREA (FT^2)	
SYMBOL	AREA
A	7.205
B	23.96
C	14.32
D	5.50
E	7.16



WEST ELEVATION



NORTH ELEVATION

SITE 3

NORTH

SCALE 0 5 10

FIGURE 6: FLOOR PLANS AND ELEVATIONS - SITE 3 (GREAT FALLS: 7598 DEGREE DAYS)

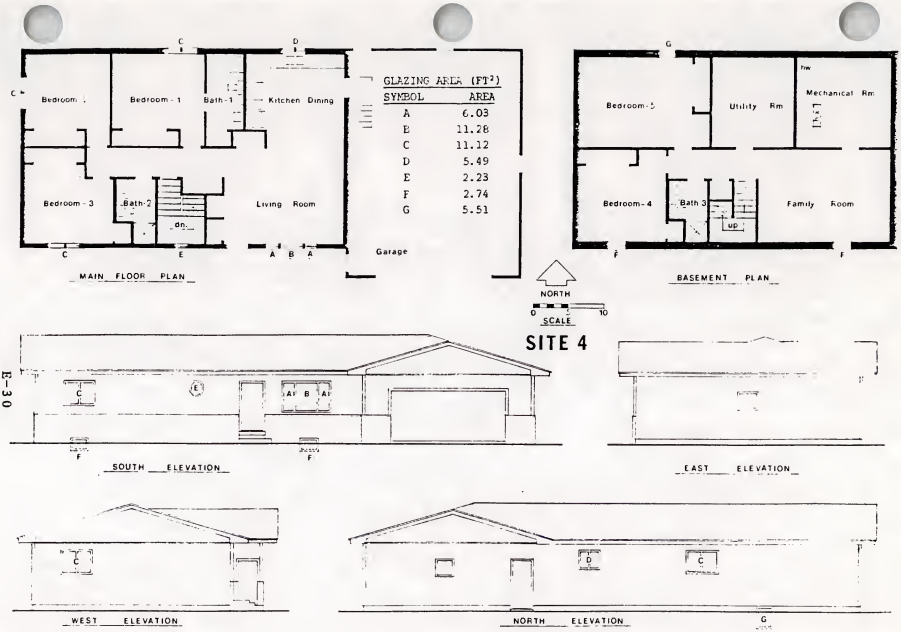


FIGURE 7: FLOOR PLANS AND ELEVATIONS - SITE 4 (LEWISTOWN: 8258 DEGREE DAYS)

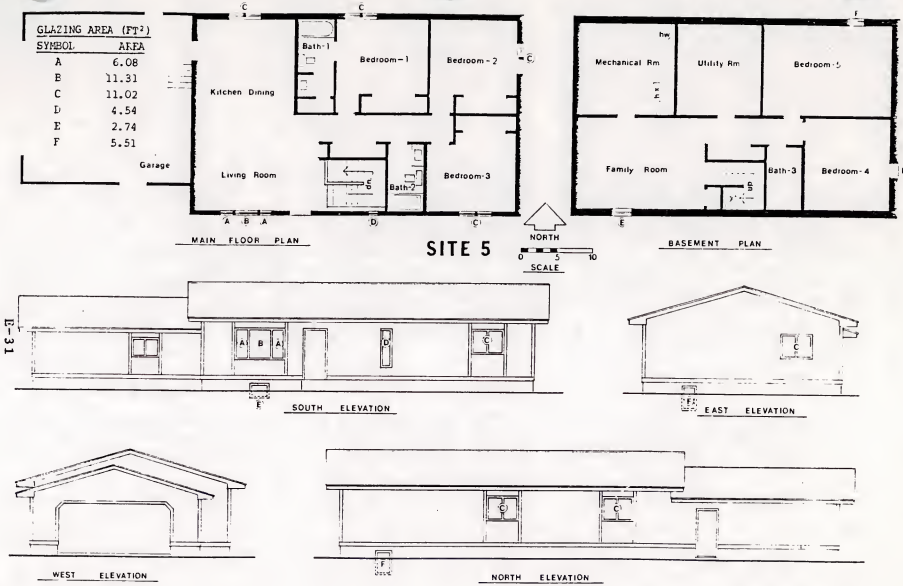


FIGURE 8: FLOOR PLANS AND ELEVATIONS - SITE 5 (BILLINGS: 7349 DEGREE DAYS)

APPENDIX B:
INSTRUMENTATION USING PERSONAL COMPUTERS

INSTRUMENTATION USING PERSONAL COMPUTERS

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ABSTRACT

Some personal computers (PC's) can provide a cost effective controller for a data acquisition system. In applications such as energy or illumination monitoring, high processing speed is not required and application programs can be written in BASIC or other high level language. Thus anyone who can write programs in BASIC can, in principle, develop a customized system with data processing and communications capability.

Based on our experience with this application area, spanning the past 9 years, we offer some general advice and comments on selecting and designing systems for this application area.

A description of a personal computer based data acquisition system currently being used for energy monitoring in Montana is included. Operational experience with this network is discussed.

1. INTRODUCTION

We began doing low-cost energy monitoring on solar heated buildings in 1977. At this time commercial data acquisition systems incorporating a computer cost between $5K and $25K. (A recent review of monitoring systems is given in [1].) We set out to design our own system in hopes of saving money. Shortly after we began our design process the first round of low-cost personal computers became available. We had the first Radio Shack TRS-80 which came to Montana.

It became clear that we could not build a cheaper computer than this one. We then set about to design an "add-on" to this machine to make it into a data acquisition system. We designed and built an analog to digital (A/D) interface which incorporated 40 channels for attaching sensors and contained a real-time clock. We added a power supply which incorporated a car battery and charger which would run the system without utility power for at least 4 hours.

We built several of these systems at a cost of about $3K each and monitored 15 buildings during the next 4 years. The systems occupied the space of a three-drawer file cabinet and weighed about 80 pounds. They were remarkably reliable, often running for months at a time without attention.

We still believe in starting with a mass-produced personal computer and adding something to it to make it do data acquisition and control work. We are not alone in this belief, a recent electronics trade magazine listed 235 add-on products for PC's.

2. WHY THE PERSONAL COMPUTER?

Using a personal computer (PC) to do real work seems to be a principle that continues to tantalize many of us. New followers "discover" the principle every day. I am not sure exactly what the attraction is all about but the words "low cost" almost always surface.

I think that PC's are perceived as being "more accessible". Almost everyone knows what an Apple, IBM-PC, etc. is and may even have one at home. If they have one at home they have probably spent many hours playing with it and are quite familiar with it. There are manuals for these popular machines written at anyone's entry level.

"Work machines", on the other hand, are for trained specialists; a select group who can decipher the operation manual written in formidable, secret language. Maybe PC's are popular for work because people feel they are more approachable.

Whatever the explanation or motivation, it is a fact that many have succeeded in making PC's do work. The technical literature abounds with articles about "How I Used a PC for etc. etc.". (You are reading another one right now). I am sure there are also many stories about ruined experiments, wasted time, spectacular failures, lost jobs, etc.; but, we don't see these stories written up in magazines.

3. WHAT IS LOW COST?

One of the inviting aspects of PC applications is the "low cost" of the machines. A more severe result of preoccupation with low cost is the "parts trap", it goes like this: "Did you know the ZX8807 chip only costs $8.23? Why with three of these and a couple of ZX044's we could build the whole thing for under a hundred dollars!".

This is the kind of talk that makes an instrumentation engineer cringe; not with fear but with a sense of deje vu. The whole business of instrumentation lays between these parts and a finished product doing some job. Design of practical circuits requires knowledge of circuit board layout, analog and digital grounds, decoupling, circuit oscillation, cabling crosstalk, ground planes, and an ability to deal with things the parts manufacturer "forgot to mention". Do not expect to bypass this territory without paying some kind of dues.

Put cost into a proper perspective. If you are a technical person or a manager working for an organization your time, with benefits, overhead, etc. is worth $100 to $300 a day or maybe more. If you are using your equipment to run a project or an experiment the cost of a failure or the cost of lost data may be thousands of dollars.

Most all of us feel good if we are "thrifty" and find a bargain or discover how to save the project money. These issues should be evaluated in the larger context; spending extra weeks or months of project time to "save" a few hundred dollars on equipment is no bargain. One of Parkinson's Laws reminds us of our tendency to be penny wise and pound foolish.

Given the cautions above I believe there are some real and important benefits to be gained with PC based instrumentation. One benefit can be low cost.

4. BE AWARE OF EMI/RFI NOISE RATINGS

Energy monitoring instrumentation is often used in residential settings. Computer (or digital) equipment generates electromagnetic radiation, EMI, which interferes with TV and radio reception. Since 1984, PC's are required to pass FCC tests for residential use before they can be legally sold. A lot of data acquisition equipment is designed primarily for industrial use in a factory and is allowed by the FCC to

radiate more noise. [2]

If a personal computer add-on is legal for residential use it will be rated "CLASS B" by the FCC. A legal instrument will always have an FCC identification number on it's enclosure and the statement;

> "Certified to comply with the limits for a CLASS B computing device pursuant to Subpart J of part 15 of FCC rules."

The system must not create interference and it is essential that it is capable of rejecting interference from other sources. A data system must record tiny signals from sensors to an accuracy of one part in a thousand, or better. Home appliances such as SCR light controls, motors in washers and dryers, heating systems, etc. generate electrical noise and radiate this energy through the air and through the 117 vac wiring in the house creating a hostile environment for the sensitive data system.

The data system should exhibit a tolerably small "drift" in its readings with time and temperature changes. Drift and noise are problems that are controlled by specifying proper equipment and then installing the equipment using good instrumentation techniques.

5. ASSEMBLING A PC BASED SYSTEM

The components for a PC based data system for data acquisition and control of building energy experiments are discussed below.

5.1 A Personal Computer

Personal computers come with a variety of features; prices range from $100 to $5,000. The features we want from the PC are a CPU, some memory, a keyboard, a display, and some input/output (I/O) connections. For typical energy monitoring tasks we can usually find these features in low-end units costing less than $1,000.

5.2 A high resolution A/D converter

There are plug-in circuit cards available for the popular PC's which will convert analog voltages into digital numbers which can be read by the computer. Units providing a 12 bit conversion (1 part in 4000) at a rate of a few conversions per second will be satisfactory. Most of these boards include multiplexers so that several individual sensors can be (sequentially) read.

For energy monitoring applications integrating A/D converters are are preferred because of their sensitivity and excellent rejection of electrical noise. The cost of these boards will typically range from around $400 to $800 or more.

Other products are designed to connect to standard RS-232 ports, bus connectors, or special instrumentation ports. The cost of these products ranges from around $400 to $2,000 or more. The more expensive products usually contain extensive signal conditioning and an internal computer.

Some A/D converter accessories are available for PC's for under $200. Some PC's have a built-in A/D converter for sensing a joystick or mouse attachment. These devices will generally not have the sensitivity or resolution required for energy monitoring applications.

5.3 Signal conditioning

The input range of many A/D converters is 0 to 5 or 10 vdc. Sensors often put out only a few millivolts so that some amplification is often required. Other sensors require a voltage or current excitation. More expensive A/D converter systems usually incorporate some signal conditioning capability which may make them cheaper and easier to use in the long run.

5.4 Battery power supply, UPS

For serious or long-term experiments it is advisable to have a battery power supply (UPS) so that the system keeps running through utility outages. The power supply should protect the system from voltage spikes and low voltage conditions. The reduced maintenance and data loss are easily worth the initial cost. Units having 1 to 2 hours stand-by capacity are available for PC's at costs ranging from around $400 to $800.

5.5 Data storage

The system will usually need some device to store data. This can be a magnetic cassette or diskette unit. Solid-state data storage modules or boards are available for some PC's. These systems, including battery-backed memory and EPROMS, offer improved reliability. Costs of add-on storage modules range from about $100 to $600. (Some PC's may have adequate data storage integral with the system.)

5.6 Real time clock

Data logging applications will usually need a real time clock so that the system knows when to scan sensors, take control actions, store data, etc. Some PC's incorporate this feature. Add-on cards containing clocks are available for popular PC's at a cost of around $200.

5.7 Other

Some experiments will use a modem so that data can be exchanged with other computers. A printer may be needed to generate reports on-site. Some PC's incorporate these features or have a port connector where these accessories can be attached. Add-on modems will cost $100 to $600 and printers cost around $300 to $700 depending on features and speed.

When selecting add-ons for a PC look for products with proven field experience; preferable in your application area. Specifications can be bewildering and misleading even when they are honestly presented.

Figure 1 illustrates a PC based system. A variety of data storage options are indicated on this diagram.

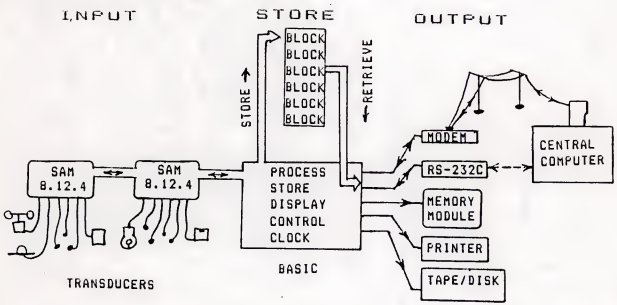

Figure 1. SYSTEM COMPONENTS AND DATA STORAGE OPTIONS

6. DESK-TOPS AND PORTABLES

During the last three years we have seen the introduction of "lap sized" computers having many of the features of desk-top computers. These units are typically the size of a notebook and will run off of internal batteries for several hours or more. They usually contain an internal clock and retain data in memory even when external power is turned off. These special features make the portable computers very appropriate and cost/effective for the applications we are addressing.

If we compare desk top PC's and portables based on their cost effectiveness as general purpose microcomputers, the desk tops win because of better displays, disk drives, and more memory. However, by the time we add an UPS, a clock, and battery powered memory to the desk top computer,it's cost may be more than the portable.

For energy monitoring applications the small size and compactness of the portable is a definite advantage. Due to it's low power dissipation and small size it can be put is a small enclosure without cooling fans or tucked into a closet or bookshelf. Short-term measurements such as illumination studies or "energy snapshot" monitoring become feasible when your entire data acquisition system can be carried in a briefcase, Figure 2.

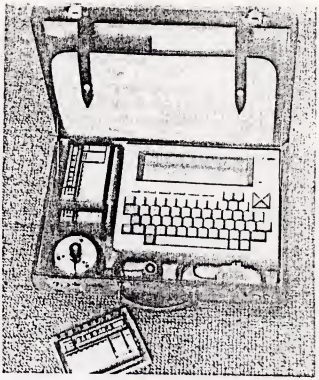

Figure 2. PORTABLE MONITORING SYSTEM

7. EXAMPLE PC MONITORING APPLICATION

Portable PC's are currently being used as a part of a data acquisition system to monitor five superinsulated residences in Montana. This program is supported be the Montana Department of Natural Resources and Conservation. The National Center for Appropriate Technology is the prime contractor and Fowlkes Engineering was responsible for designing and installing the instrumentation systems.

The instrumentation schematic for these buildings is shown in Figure 3. These sensors include five pulse initiating kWh meters, a solar radiation sensor, two status sensors, a DHW flow meter, and 8 temperature sensors. A total of 17 sensor channels are monitored each few seconds.

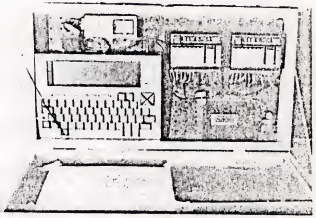

Figure 4. SITE INSTRUMENTATION SET

8. HARDWARE AND SOFTWARE

The instruaentation hardware is shown in Figure 4. A NEC 8201A portable computer with 32K of memory is connected to two SAM 8.12.4 Portable Data Acquisition Modules manufactured by Fowlkes Engineering. An external battery capable of running the entire system for 50 hours was used. A BASIC program occupying about 6K of memory controls the system. The entire system is enclosed in a box about the size of a briefcase which is attached to the wall in the basement. The current cost of the components in the box is around $1,500.

The system averages the data at the end of each hour and stores these averages in it's (battery maintained) memory as an ASCII file. The memory capacity used in these units has room for at least 13 complete days of hourly average data.

The data acquisition computer is connected to an auto-answer modem which shares the existing residential phone service. The system "needs" the phone line less than 15 minutes each week. Sharing the phone line saves unnecessary expense. The computer program controls when the modem can answer the phone. Each site is programmed to allow the modem to answer the phone only during a specific 20 minute period each day.

The data analysis sub-contractor for this project is Ecotope, located in Seattle, WA. Ecotope calls each Montana site once a week, using an IBM-PC, and retreives the previous 7 day's data. The IBM-PC archives this data on disk. The data transfer for one site-week takes about 12 minutes of phone time. Since the site computer buffers 12 days of data Ecotope can slip their schedule for up to five days before data is lost.

Programs for transferring the data use checksums to detect transmission errors. If an error is detected, the data is re-transmitted until it is correct. Within Montana we have found that on the average one line of data must be re-transmitted (due to an error) out of each 30 pages of data. This is better than expected and is a insignificant overhead burden on phone connect time.

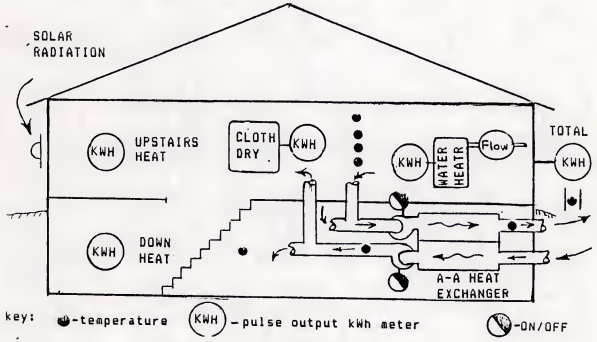

Figure 3. INSTRUMENTATION SCHEMATIC

9. SENSORS AND WIRING

Semiconductor temperature sensors, Analog Device's AD-590, are used on this project. These sensors were individually calibrated before installation to an average precision of +/- 0.2 degF.

Solar sensors were Li-Cor 200S photovoltaic units. We used the factory calibration which is +/- 5% or better. Fan status sensors were solid-state, optically isolated devices manufactured by Fowlkes Engineering. Electric power was measured by Duncan type MS meters having PG6-MP1/15 pulse adapters. The resolution was one pulse each 0.108 kWh. Flow of DHW was measured with a Rockwell meter having a pulse register producing one pulse/gallon.

Sensor extensions were roughed in by local site contractors using commonly available thermostat wire. This departs from usual and prudent instrumentation practice of using shielded sensor wires. We were able to get by with this because of the excellent noise rejection of the SAM 8.12.4 data acquisition unit. I can not generally recommend this short-cut but it saved hundreds of dollars in wire cost and inconvenience in this project.

The sensors were installed and the systems started and put on-line by Fowlkes Engineering in December 1984.

10. COMPARISONS

Table 1 shows some comparisons of average ambient temperature and solar radiation for the Great Falls sites.

TABLE 1. AVERAGE DATA COMPARISON [3]

January	Site 1	Site 2	Site 3
Temp, F	21.52	20.20	21.42
Solar,Btu	1126	1203	1161
February			
Temp, F	23.37	21.90	23.55
Solar	1179	1268	1266

Sites 1 and 3 are located at the same elevation, near the Missouri river, and are about 2 miles apart; we expect the ambient temperature at these two sites to be similar. The average ambient temperatures reported by the data acquisition systems for both months agree to within 0.2 deg F. This is within the calibration precision discussed in Section 9. Site 3 is located on a bench several hundred feet higher in elevation. The data system shows monthly average temperatures about 1 deg F lower which is plausible.

The solar radiation measured at Site 1 is lower for both months. Site 1 faces about 30 deg east of true south while Sites 2 and 3 face nearly south. The orientation would explain this difference very well.

The solar radiation data at Sites 2 and 3 agree exactly in February while Site 3 is 3% lower in January. Since Site 3 is down by the river, it is shaded by the surrounding hills during early morning and late afternoon; an effect that would be proportionaly greater near the winter solstice. Site 2, being on the top of the bench has insignificant shading and is less likely to have local fog.

The comparison of environmental data at the three Great Falls sites is in close agreement. Small differences can be reasonably explained by expected microclimate effects and known shading differences. These comparisons give us confidence in the integrity of the data base.

11. INSTRUMENTATION PROBLEMS

Problems are the most interesting part of a project; provided you don't have too many of them and provided you can solve them. We have an intermittent noise problem at one site in Great Falls. This site is lined up with the runway of Great Falls International Airport and shares a plateau with military radar sites. Occasionally

"something" gets turned on which floods the site with high frequency energy having a period of 4 seconds; probably a rotating radar transmitter.

The peak ac noise is over 450,000 microvolts rms in each sensor wire. (The data system is resolving signals as small as 50 uv thus the noise is 10,000 times larger!) Fortunately the data system rejects most of the noise and the noise is present only a few hours each week. The worst damage to the data due to this noise is the solar sensor which reads a few percent low if the noise is present during the daytime.

There were two instances when a site computer has stopped running and turned itself off with no apparent error condition. One case was shortly after start-up in December 1984 and the other was on April Fools Day in 1985. This type of halt would occur if the ac power to the computer was off for more than two days. (The computers turn themselves off on a failing power condition and save all data.)

In one instance the homeowner had been working on his wiring but can't be sure this was the explanation. In both cases the system was easily restarted by instructing the homeowner to turn on the computer and press the RUN key.

As of the first week in April, 476 complete site-days of data have been gathered. About three days of data were lost due to the problems described above. There have been no known failures of temperature, status, solar radiation, or flow sensors. At this point the batting average of the data acquisition system and the modem data retrieval is a respectable 99.4%.

The kWh meters had an auspicious start, being delivered two months later than promised. Out of 25 kWh meters currently on-site, 4 meters have failed. Two meters were adjusted locally and two were returned to Duncan. After returning from the factory one of these meters still had a rotor which only turned intermittently.

The poor performance of the Duncan kWh meters in our experiment has been our primary source of missing data. The Duncan factory took two and 1/2 months to repair the two meters we sent back and one of these still does not work. We did not expect these failures and did not have spares available.

We have been fortunate that all the Duncan meters which have failed have, by chance, been in sub-meter positions. Missing data here is less damaging to the analysis. The "total power" kwh meters are connected in series with the billing meters used by Montana Power Co. Comparisons between these two meters on all sites show average differences much less than 1%.

12. CONCLUSIONS

(1) Personal computers, when interfaced to appropriate add-on products can be useful for data logging in energy monitoring experiments.

(2) The general category of "PC based data acquisition systems" includes hundred's of combinations of hardware that is currently available. The user must think through his particular experiment to define his requirements in some detail. A vendor who has experience can be very helpful in suggesting economical approaches.

(3) For residential energy monitoring, be sure to select only equipment that is certified as "Class B" by the FCC.

(4) The superinsulated building monitoring project in Montana has produced a sizable base of very good quality data at reasonable cost. This project uses PC's with a data acquisition add-on which combine into a very cost-effective system.

(5) During the first five months of the Montana monitoring project the data acquisition systems have run continuously, with no known faults, for 99.4% of the time.

(6) The primary source of problems and lost data in the Montana monitoring project has been faulty kWh meters.

12. ACKNOWLEDGEMENTS

Montana DNR&C and NCAT are gratefully acknowledged for their support for instrumenting the superinsulated building monitoring project. Preparation of this paper was supported entirely by an in-house grant from the Fowlkes Engineering Philanthropic Fund.

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APPENDIX C:

APPLIANCE AND LIGHT ENERGY AUDITS FOR THE MONTANA SUPERINSULATION PROJECT

Appliance and Light Energy Audits for the Montana Superinsulation Project

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ABSTRACT

The National Center for Appropriate Technology (NCAT), as part of the Montana Superinsulation Project, is collecting thermal performance data from five similar superinsulated houses in eastern Montana. Over eighteen months of hourly data are on file for each of the houses.

Appliance and light operation is now seen to have a major impact on both the total energy consumption and thermal performance of the project houses. Of the three houses occupied for over one year of the monitoring period, over 53% of the total building energy consumption is used for appliances and lights.

Monitoring of each appliance and light is not practical; over 50 data channels would be required for the typical house. Of the 17 data channels available in the present project, 2 are dedicated to appliances and lights. Audits for the appliances and lights are now seen to be a reasonable way to study this portion of the house energy consumption.

Presented here are the audit and estimating procedures, accuracy of the results as compared to measured energy consumption, and estimated data.

1. Introduction

Appliances and lights (hereafter abbreviated A&L) have a major impact on the total energy consumption of typical U.S. Housing. In the newer, more thermally efficient superinsulated houses, this impact is greatly amplified. Of the three houses in the Montana Superinsulation Project which have been continuously occupied for over one year of the monitoring period, over 53% [1] of the total building metered energy consumption went to (A&L). This compares to 26% of total energy consumption for heating. Thus the total consumption for (A&L) is well over twice that for the heating system in these houses, and this in the cold Montana climate.

Heating equipment and A&L operation interact in important ways in these houses. Both contribute to the heat required to warm the house, so that a change in A&L energy will cause some change in heating equipment energy. Due to the thermostat controls, equipment is more efficient than A&L at warming the house so that a reduction in A&L energy will cause a measurable but smaller increase in heating equipment energy. This interaction is accounted for in most projects which have

[1] Work performed under the auspices of the State of Montana Department of Natural Resources and Conservation, Energy Division.

addressed optimization of the level of thermal insulation by assuming a constant value for A&L energy consumption before proceeding with building modeling. If this assumed value is too large, a portion of heating equipment energy is offset, the resulting savings from added thermal insulation are reduced, and the resulting 'optimal' amount of thermal insulation is artificially low. High assumed values of A&L energy have the opposite result.

Aside from the absolute value of the A&L energy, other important areas need to be addressed:

1. Do seasonal variation in lifestyle and building environment cause annual trends in A&L energy consumption, and if so, what are their causes, magnitudes, and phases?
2. Do long-term changes in lifestyle and appliance efficiencies have corresponding effects on A&L energy consumption?
3. What are the potential impacts of efficient A&L technology and modified life-styles available now?
4. What are the factors causing tremendous house-to-house variation in A&L energy consumption?
5. What is the elasticity of the A&L energy market; to what extent would energy price increases cause reduction in non-essential energy consumption or cause hardship?

The Montana Superinsulation Project is providing a unique opportunity to begin approaching these questions. While several projects in the literature provide valuable data from the monitoring of limited numbers of specific appliances[2], cost constraints continue to prevent the detailed monitoring of A&L energy in homes. Over fifty data channels would be required to monitor each appliance and light in each of the Montana Superinsulation Project houses. At present, two channels per house are dedicated to A&L energy consumption, including clothes dryer energy and all other A&L.

in lieu of direct measurements of each appliance and light, audits are seen as a possible way to gain a quantitative view of the detailed A&L energy consumption profile.

2. AUDIT PROCEDURE

The audit procedure is divided into three basic steps:

1. Inventory of appliances and lights in the house.
2. Interview occupants as to use of each individual item in inventory.
3. Assign monthly energy estimate for each item in inventory.

The first two steps are done at the house site, and typically take about three to four hours to complete. At the present level of experience, no electric device is considered to be too small to be included. Items of importance are sometimes found

buried in a closet or storeroom. Appliances or lights in garages (attached or detached) and outdoors must be included. Care must be used when moving stereos and televisions to access label data, as furniture and nicknacks can easily be damaged. A detailed summary to the occupant of what is taking place can reduce apprehensions about searches through closets and the bottom of the refrigerator. Lampshades must typically be removed from all ceiling and wall light fixtures to obtain bulb watt ratings. Typical items found by category are shown in Table 1.

The interview requires 15 to 30 minutes. Each item on the inventory is brought up. Different time frames are used for different items; some lights are used 'hours per day,' others are used times per week @ hours per use. When difficulty is encountered by the occupant, the suggestion of a different time frame can often help make things easier. Occasionally the occupant can add an often-used item that was missed during the inventory such as a curling iron which was buried in a closet or drawer. Use of lights will automatically be given for the time of year of the interview; care must be taken to not include uses of typical of other times of the year for fans, ranges, etc.

The monthly energy estimates are assigned using both published data and engineering estimates based upon experience. As more experience is gained with the procedure, a 'cookbook' approach should evolve which should increase consistency between estimates. Data from the Association of Home Appliance Manufacturers, California Energy Commission, American Council for an Energy Efficient Economy, manufacturer data sheets and catalogues and others is helpful in assigning estimates of energy use for listed appliances like refrigerators. This data can be modified for different operating conditions, such as loads per week for dishwashers or freezers in unheated garages. Incandescent lamps are rated at their label watts times interview usage. Waterbed heaters on thermostats and variable output devices like stereo power amplifiers are rated on a 'best guess' basis. The data is recorded and summed on a monthly basis, and should be considered as an estimate only for the month during which the estimate was made. The present audit form is shown in Table 02.

3. AUDIT ACCURACY

Plots of the measured and estimated A&L energy are presented in Figure 1*. Note that the measured A&L energy varies month-to-month for most sites. For the three houses for which measured data is most complete, the March estimate is quite close to the annual measured average. This is a pure coincidence, based upon the chance that the annual variation in A&L energy averages to about the March value. A more meaningful comparison of the three audits' accuracy is the March measured value. As seen in Figure 1, these March values are also quite close, within about 15% by the measured values. Added

*Note: For the duration of this report, A&L energy excludes clothes dryer energy, which was nomitored separately for this project.

confidence in the estimates is gained by noting that the largest of the three March values is about 50% bigger than the smallest, and that even with this variation, the above-mentioned 15% accuracy is obtained. While measured data for September is not yet available, we can see in Figure 1 that the estimated values are at least of the same general magnitude as the measured values for these sites during earlier months.

Table 03 contains data on the variability of the measured data on a total daily basis for the audit month. Note that the actual daily data varies with a standard deviation of 8 to 23 percent. It appears that the audit interview process is a surprisingly good averaging technique for this variable data.

Based upon this experience to date, it appears that the accuracies achieved are based upon more than pure luck. If this is true, then it follows that the individual components from which the total estimate is formed achieve approximately the same accuracy. While more estimates need to be done to statistically prove the accuracy of the methodology, the existing data do not shed doubt upon it.

The clothes dryer data, which would under other circumstances be a part of this estimate, may be difficult to estimate, due to the different possible control settings and operating modes. Since this number is also relatively large in most cases, the accuracy of the total results in such cases may be a problem. This recently identified problem may be reduced by finding appropriate questions for use in the interview.

4. AUDIT DATA

Estimated energy end use by category is represented in Table 4 and Figure 2. This data will first be discussed on a category basis, and then house-by-house.

Refrigeration dominates as the major end use category at three sites. A refrigerator/freezer and a chest-type freezer is the prevalent refrigeration package. Food preparation is the most frequent occupant of the second- ranking category. Only one site has the occupants eating outside the home more than rarely, and two or three hot meals per day are the rule. Air quality equipment consists only of Heat Recovery Ventilators in this sample. Even though this equipment draws less than two amps, if used continuously the power consumption is significant. Occupant interaction accounts for the house-to-house variation, as all units are identical. Lighting also consistently appears as a relatively large category. The housekeeping (excluding clothes dryer), entertainment, and other categories are most typically relatively small energy consumers. The addition of the clothes-dryer to the housekeeping category would, however, make that category comparable to the other largest energy users.

Perhaps the most interesting feature of the ranking of end uses, when compared house-to-house, is the variability. No two houses have the same ranking order. This is due more to the the characteristics of the house occupants than the appliances or lights found in the houses. In some sense comparisons between houses, even in the same month, are unfair. During the inventory procedure, the auditor is bound to find partially disabled ventilation systems, empty refrigerators (typically an energy hog) running in the basement, etc. Statements like, "If house A were properly ventilated, it would have the same air quality energy consumption as house B," continually confront the auditor.

But the objective here is to estimate what actually happened in the field, and only secondarily judge if the house operating modes are appropriate. Data from studies like this one can later be used in the design of consumer education materials. After such programs are implemented, perhaps auditors will be able to find ideal, or typical operating conditions in the field.

Site 2 inspires little comment, other than the fact that the smaller light load reflects the fact that only two persons, and especially no children occupy this house.

Site 3 has two freezers and two refrigerators. The large food preparation estimate reflects the large amount of cooking and baking done at this site.

The main feature of the Site 4 data is the lack of air quality category energy consumption. This and the Site 5 audit were performed in September instead of March, and the site 4 occupants still ventilated their house by opening windows. A relatively efficient refrigerator, and energy-saving lifestyle (unused lights turned off, and stereo used during the day rather than TV, etc.) make this the smallest of the five A&L audits.

Even though visited in September, the Site 5 occupants were ventilating their house with the heat recovery ventilator. An energy-hog refrigerator in the basement and the presence of a baby (increased lighting) keep this house from having the smallest total estimated A&L energy use of the five houses.

The measured data in Figure 1 raise some interesting questions which are unfortunately beyond the scope of this paper. It appears that all sites except Site 3 exhibit a strong periodic variation in A&L energy use, with a maximum occurring in winter and a minimum in summer. We know that the energy consumption of most refrigeration systems is also on an annual cycle, but totally out of phase with the measured data (refrigerators use less energy when the environment is cooler in winter). This is evidently a small effect when compared with the variations caused by seasonal changes in lighting, food preparation, air quality, and entertainment, which are expected to be smaller in the summer months. But why does Site 3 exhibit a nearly

constant month-to-month consumption? Is the largest consumer automatically the most stable? But Site 1, the second largest consumer, is highly periodic. Perhaps some function of the energy distribution by end use is unique to Site 3. Perhaps the large refrigeration load counteracts the other seasonal tendencies. Additional audits of the same sites at other times of the year may be the only way to answer these questions.

CONCLUSIONS

Appliances and lights are proving to be the largest energy consumers by far in the Montana Superinsulation Project. This energy is over twice the quantity required for operation of the building heating equipment. Audits of appliance and light energy consumption, consisting of an inventory, occupant interview, and subsequent calculations, are proving to be an effective way of studying this energy consumption, in lieu of very expensive detailed monitoring. To date, estimates derived by this method have predicted within 15% the total measured energy consumption in this sector. The results of these audits suggest that a 'typical' house is hard to find. The operation modes that are expected, or 'should be' found are often lacking.

Proposed future work includes the performance of audits on additional houses to provide a more meaningful statistic analysis of the accuracy of the method. More work will also be done to determine operating modes and more efficient appliances which could have an impact upon appliance and lights energy consumption.

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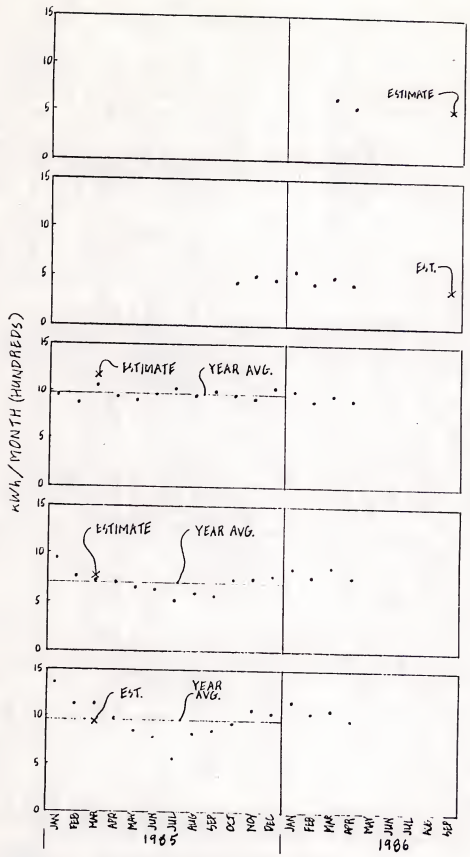

Figure 1. Monthly energy consumption, appliances and lights, excluding clothes dryer.

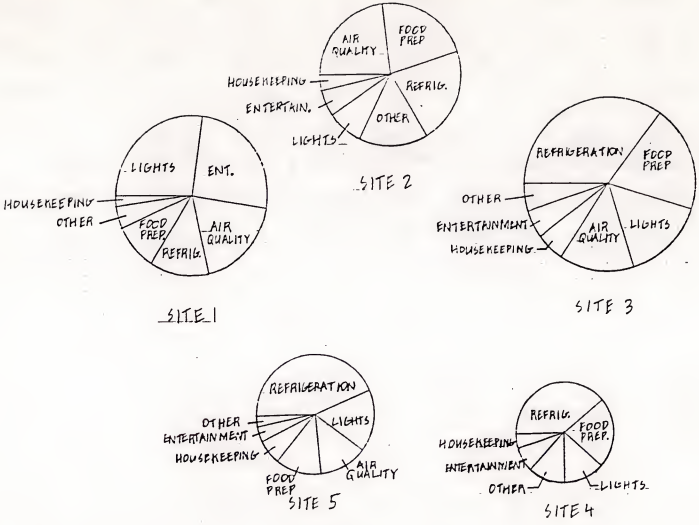

Fig. 2. Estimated energy by end use category. Area is proportional to energy. Sites 1, 2, and 3 represent March, and sites 4, and 5 represent September.

REFRIGERATION	refrigerator- freezers freezers
FOOD PREPARATION	range oven and cook-top microwave coffee maker slow cooker (crock pot) electric fry pan toaster can opener blender popcorn maker
LIGHTING	table/ floor lamps built- in lamps night lights
AIR QUALITY	ventilation fans range hoods air purifier humidifier
ENTERTAINMENT	television & accessories video recorders stereo and accessories radios hot tub
HOUSEKEEPING	clothes dryer clothes washer dish washer vacuum cleaner trash compactor garbage disposal
OTHER	water bed heater electric blanket clocks battery chargers personal hygiene products mechanical tools lawn tools

Table 1. Typical inventory items by category.

ENGINEERING STUDIOS

APPLIANCE/LIGHT ENERGY AUDIT

PAGE 01 OF 02
AUDIT DATE 10/24/82
AUDIT LOCATION SITE C4 MAIN
AUDITOR DAH

LOCATION	APPLIANCE OR LIGHT	TYPE	BRAND	MODEL	DOE RATINGS: THIS MODEL	DOE RATINGS: OTHER BRANDS/MODELS: WORST	DOE RATINGS: OTHER BRANDS/MODELS: BEST	USE	LABEL POWER	ESTIMATED MONTHLY ENERGY, KWh
	REFRIGERATOR/FREEZER	2 DOOR W FREEZER ON TOP	GE	TBH5BB	1004 kWh/yr			CONTINUOUS		84
	RANGE		SEARS	911-41777710				3 HRS EVERY DAY		85
	COFFEE MAKER	W/ WARMER	MR COFFEE	CB-100				THICE/DAY	1125 W	0
	BLENDER		OSTER	971-CCA				ONCE/2 DAYS	450 W	0
	CAN OPEN/ SHARPENER		RIVAL	740				THICE/DAY @ 15 SEC	2A	1
	MICROWAVE		AMANA	RRL-9TA				4 MIN/DAY	1500 W	3
KITCHEN	RADIO	PORTABLE 12 V	GE	—				1 HR/DAY	—	0
	BATTERY CHARGER		SAFT	CC-1				CONTINUOUS	6W	4
	WASHING DISHES BY		INSINKERATOR	V-11				2x3 USE C/ DAY	6.7A @ 120	0
	CEILING LIGHTS	INC.						2.5 H/DAY	200 W	16
	TABLE LIGHT	INC						2 H/DAY	120 W	7
-	---	— —							KWH TOT	(700)
	STEREO	RECEIVER	PIONEER	SA-450				6 H/DAY	90 W (ASSUME 50 W AVG)	9
	TURNTABLE		DUAL	4600 WX				1 HR/MO	—	0
	VCR		RCA	VHP460T				3 HRS/WK	40 W (TAKES ALWAYS UNDER 40W)	6
	TELEVISION	26" DIAL (COLOR, REMOTE)	SEARS	564-49166 356				4 H/DAY	2.4 A MAX (IS W AVG)	14
	E TABLE LAMP	INC	SEARS					3.5 H/DAY	60 W/150 (ASSUME 100)	11
	E TABLE LAMP	INC						NONE	100 W	0
LIVING ROOM										(42)

Table 2. Sample audit form.

1 FLUOR. FIXTURE; LIGHTS CAN BE USED INDEPENDENTLY

		MEASURED		ESTIMATED	
SITE #	MONTH	AVG. DAILY CONSUMPTION	DAILY TOTALS STD. DEV. %	AVG. DAILY CONSUMPTION	ESTIMATE-MEAS. AVG. ERROR
1	MAR	36.7	23%	30.9	-15%
2	MAR	23.4	19%	25.2	+ 6%
3	MAR	34.5	8%	37.8	+10%
4				12.7	
5				17.7	

Table 3. Measured daily data, standard deviation, audit estimates, and audit accuracies. Consumption is kWh/ day.

	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
REFRIGERATION	121	169	410	154	240
FOOD PREPARATION	92	170	232	89	67
LIGHTING	259	64	183	52	93
AIR QUALITY	180	180	160	0	74
ENTERTAINMENT	245	46	61	31	22
HOUSEKEEPING	23	29	64	19	37
OTHER	38	123	61	48	17
TOTAL	958	781	1171	393	550
ESTIMATE ACCURACY	-15%	+6%	+10%	NA	NA
MONTH	MAR	MAR	MAR	SEP	SEP

Table 4. Estimated energy by end use category. Clothes dryer not included. All numbers kWh/ mo.

APPENDIX D:

PRELIMINARY PERFORMANCE ASSESSMENT OF THREE VENTILATION SYSTEMS EMPLOYING AIR–TO–AIR HEAT EXCHANGERS

PRELIMINARY PERFORMANCE ASSESSMENT OF THREE VENTILATION SYSTEMS EMPLOYING AIR-TO-AIR HEAT EXCHANGERS

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ABSTRACT

Similar ventilation systems employing air-to-air heat exchangers in three of five virtually identical houses in Eastern Montana are discussed. A brief history of the system design and machines is presented, as well as information on the system design and installation. Preliminary measurements are discussed, and observations based on performance data collected over approximately three months are presented. Occupant behavior and response is reported, and a preliminary assessment of the state of the art is given. Finally, recommendations for future studies are offered.

INTRODUCTION

During 1979-82, staff and contractors of the National Center for Appropriate Technology (NCAT) did research that led to the issuance of several highly-detailed experimental house plans that featured central ventilation systems employing air-to-air heat exchangers. The experimental plans were designed for climates where 7,000 heating degree days or more are the norm.

At the time of the development of the first plan (1980-81), air-to-air heat exchangers of residential scale were not readily commercially available. (At this time, most people wanting to use the technology for residential applications built do-it-yourself models.) In addition, professional expertise in low-flow, small-scale ventilation systems was hard to find.

NCAT staffers finally located a commercially available residential-sized heat exchanger for specification in the first of these house plans. This machine had no automatic defrost control.

Ventilation strategies from commercial buildings were studied and reviewed, and the design team opted for a centrally located heat exchanger that delivered supply air in the house to all areas by use of a central ceiling pressure plenum, with several stale-air exhaust points in living/dining and baths. These initial ventilation system drawings were sent out for professional review. Most reviewers were positive and had no additional comments on the system design.

However, one reviewer said that a centrally located, ducted system was not necessary, and that a single, through-the-wall air-to-air heat exchanger would probably suffice.

In 1982, two NCAT contractors issued another set of house plans for a larger house. Within this time frame, the air-to-air heat exchanger industry had expanded a bit, and a different unit with some manner of semi-automatic defrost was selected for specification in this second plan.

In mid-1983, NCAT staffers surveyed the residential heat exchanger industry again, and found more than 20 companies in the business. A review of literature and interviews with manufactureres showed that most companies could offer little or no design assistance, nor did they have available installation information or operation information. In addition, a number of machines had no defrost control. None had undergone formal testing, and no standards for heat exchanger performance existed, although one industry group said at the time that it was its goal to get a formal performance and testing process into place.

In 1983, NCAT proposed to the Montana Department of Natural Resources and Conservation Energy Division that a number of the NCAT experimental houses be built and monitored in Eastern Montana. In April 1984, the Montana Superinsulation Project began, with the first step being to again turn to the air-to-air heat exchanger industry for its current input to the use of these devices in the project houses.

The 1982 version of the house plan (for a ranch-style, three-bedroom, two-bath house with basement for a total of roughly 2,400 sq. ft.) was again sent to several heat exchanger manufacturers for their review of the system.

Several changes were suggested by NCAT and the manufacturers that were incorporated into the final version of the house plan for use in the Montana project. These changes were aimed at improving the ventilation and are, for the most part minor. They included:

* having both supply and exhaust ducts from the house exit through the rim joist on the north side, rather than having the exhaust go through the roof;
* 4" duct was enlarged to 5" duct for return air ducts from bathrooms and kitchen;
* the return air grill from the living/dining area was moved into the kitchen;
* supply air to bathrooms was eliminated as being unecessary.

Of the five sites, two (site 2 and 3) were built from the unrevised plan, while Sites 1, 4 and 5 were built from the Montana project plan.

Yet, as built, the systems are more similar because of changes made by builders. (Builders at Sites 2 and 3 changed the intake and exhaust ports to go through the rim joist, rather than putting the exhaust through the roof anyway.) However, Site 3 placed these ports on opposite sides: supply from the south, exhaust to the north, while Site 2 put both ports on the north side.

This paper will highlight the systems in Sites 1, 2 and 3, because the three are in the same city and the most data is available on these sites. Later reports will address Sites 4 and 5.

MACHINE AND SYSTEM DESIGN FEATURES

Both the Montana Superinsulation Project house plan and the earlier Plan 2 specified the use of a specific heat exchanger, the VanEE R-200, to be located in the mechanical room in the

basement. (This heat exchanger was first introduced on the market in late 1981, and is currently being supplanted by the manufacturer with a new unit, the R-2000.)

The R-200 features two 95-watt centrifugal type "squirrel-cage" fans, a double cross-flow core, and defrost activated by the temperature of the air entering the house after it has passed through the core. The manufacturer's literature rated the machine's capacity at 250 cubic feet per minute (cfm), without ductwork.

The ductwork system in the Montana project plan (see Figure 1, next page) features galvanized 5" and 6" round ducts for stale air return from kitchen, baths and laundry area to the machine. Fresh air supply is accomplished with a dropped-ceiling pressure-plenum for each level. The plenum is made of sheet rock, with openings covered with adjustable registers. These fresh air supply registers are located over the doors to each bedroom and the main living area. Their placement is designed to keep this potentially cooler air from causing occupant discomfort and to facilitate air flows and mixing.

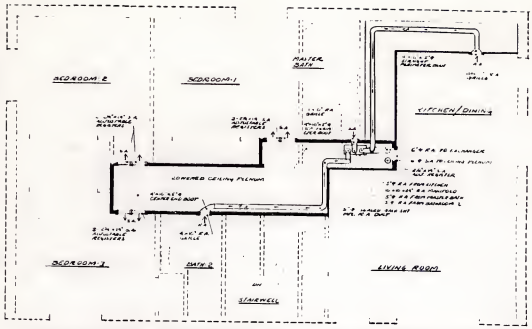
The machine's operation is controlled by a variable speed controller that is typically to be set at the "low" speed for continuous operation. High speed override is activated in two ways - a dehumidistat and auxillary timer switches in the bathrooms.

While no detailed engineering projections were possible, the ductwork design was geared toward drawing stale air toward the kitchen and baths (rooms with cleanable surfaces and away from the living area where most occupants might spend the most time), while delivering fresh air to other areas of the house through the low-cost pressure plenums on each level. The goal was not to attempt to design a "perfect" system, but rather a system that could be built with materials and skills available in all areas of the nation where the plan's use might be appropriate.

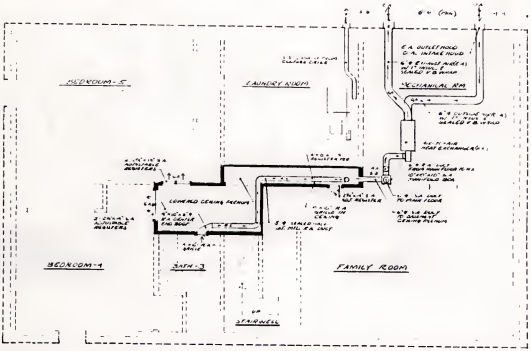
INSTALLATION AND SYSTEM BALANCING

Given the detail of the project house plans, which include a highly specific isometric drawing of the system, project builders reported no installation problems during the construction phase. However, because Sites 2 and 3 were built from the unrevised plan, neither builder had access to technical assistance offered to the other three builders because they were not part of the original sample during this part of the construction phase.

In late December 1984, a manufacturer's representative was sent out to balance the air flows at the four sites. Equipment problems made this impossible, and NCAT staffers and a contractor made an attempt at balancing the air flows and getting some rough indication of total air flows. Later measurements were taken using a hot-wire anemometer and hood on two separate occasions by different NCAT contractors. These preliminary measurements were performed to give a rough indication of total air flows and balance of air flows. Due to poor measurement conditions (high or gusting winds and lack of straight duct runs) the measurements have a high range of potential error. Within the range of accuracy of one-time measurements taken to date, it is not possible to say whether the system air flows are imbalanced, or what the actual total air flows are. But, the range of the three measurements indicates that air flows probably not far out of balance, and that total air changes per hour (ach) due to the mechanical ventilation



1ST. FLOOR PLAN - DUCTWORK LAYOUT FOR AIR EXCHANGER THRU LOWERED CEILING PLENUM



BASEMENT PLAN - DUCTWORK LAYOUT FOR AIR EXCHANGER THRU LOWERED CEILING PLENUM

FIGURE 1: Ductwork layout for ventilation system employing an air-to-air heat exchanger from Montana Superinsulation Project house plan.

system could be estimated to be in the .3 - .5 range. Infiltration rates in these houses are extremely low, ranging from slightly over 1 ach at 50 pascals to about .5 ach at 50 pascals.

It is clear that the balance of the air flows changes somewhat with fan speed. However, further changes can result from changes in weather and occupant actions. Balance may be affected by wind effects, temperature of the air flows, positioning of interior doors and adjustable registers over the duct openings, as well as changes in fan speed. These parameters could be documented with continuous air flow measurements and moisture measurements.

It is clear from other projects that major air flow imbalances could be the cause of substantial problems. Reported phenomena range from the major problems that can stem from extreme pressurization (visible ice formations on the house exterior at air leakage points) to a variety of symptoms (such as large hoar frost build-up at the outside exhaust port) that could stem from negative pressure. Imbalances often result in reduced heat transfer, which can lead to occupant discomfort, as well.

Whether minor (and constantly changing) levels of imbalance cause any problems worthy of concern has not been well established. But, it is thought that if the level of imbalance is in an acceptably narrow range, no problems or major effect on performance will occur. It should be noted that this range of "acceptable imbalance" has not been well established to date, nor can it be established without further research and analysis.

During the course of the Montana Superinsulation Project to date, no problems have been noted that could be related to apparently minor air flow imbalances. Despite differences in one-time measurements of velocity and balance between the three Great Falls houses, the three systems have performed with remarkable similarity, with supply and exhaust temperatures typically ranging no more than about 5°F and often less.

CONTINUOUS MEASUREMENTS: PRELIMINARY OBSERVATIONS

All five houses in the Montana project have the following instrumentation that relates to the the air-to-air heat exchanger: two temperature sensors are dedicated to continuous temperature readings on the exhaust and supply air streams immediately after each air stream has passed through the core. Fan status is measured to measure the onset of defrost. Indoor temperatures in the houses are measured at five locations in each house, including one temperature sensor in the basement. Ambient temperatures are measured at each site.

While useful, the measurement scheme is insuffient to accurately guage the performance of the machines. In order to accomplish this, additional temperature sensors, moisture measurements and continuous air flow measurements would be advised. In addition, detailed indoor air quality measurements will be necessary to accurately judge the ventilation effects of these systems.

Yet some observations are safe to make based on the initial data from these houses.

The data shows the three Great Falls systems perform very similarly in nearly all regards (discounting occupant-caused variations). Temperature agreement is typically close (See Table 1).

TABLE 1:

TEMPERATURE RANGES RECORDED DURING FOUR SELECTED DAYS ACROSS THE THREE SITES GREAT FALLS

	AMBIENT	SUPPLY AIR	EXHAUST AIR
Day 361:	5° F	50-55° F	37° F
Day 10:	15° F	41-45° F	37-42° F
Day 6:	25° F	60-62° F	43-47° F
Day 17:	40-43° F	65-67° F	54-56° F

DEFROST NOTES

Fan status sensors indicate that all three machines typically go into defrost mode at about 0°F, and that manual defrost is necessary during prolonged periods of sub-zero temperatures. Defrost in the R-200 is accomplished by a temperature sensor, which measures supply air temperatures after passing through the core. In defrost mode, when temperatures fall below about 41°F, the supply fan is shut off and stays off until the temperature rises to about 56°F. The exhaust fan's continued operation depressurizes the house and blows warmed air through that side of the core to melt the ice. The manufacturer's manual suggests manual defrost (accomplished by the occupant removing the cold-air supply duct to the unit and allowing warm room air to cycle through the unit) may be necessary when temperatures stay below 0° F for extended periods of time.

In order to meet the suggested Canadian standard that requires that defrost operation not change the pressure balance of the house, the manufacturer has introduced a retrofit kit that alters this defrost mode. When supply air temperatures reach a set low point, the exhaust fan is shut off, and the supply fan continues to pull warm room air through the core through use of a motorized damper box that shuts off cold, incoming air until the ice has melted. This device mimics automatically the effect of the manual defrost, and seems more likely to completely melt the ice than the previous method defrost control. It also has the advantage of avoiding changes in pressure balance.

During site visits during very cold weather (-10°F to -20°F) in February 1985, manual defrost was perrormed at two of the sites. About one gallon of water exited the machine during this defrost, which took about 20-25 minutes. However, not all the water could leave the machine, because the "cold side" of the core doesn't have its own drain. (Theoretically, the moisture is supposed to be isolated on the "warm side" of the core.) How this moisture and ice accumulates on the cold side of the machine is unknown. Several possible causes include condensation from basement air leaking into the unit from a loose-fitting duct attachment or cross flows from the "warm side of the core" to the cold side. This moisture must be mopped out at the time of defrost. (The later VanEE unit provides a drain on both sides of the core.)

A later site visit in March found the cold-air supply duct's flex-duct fiberglass insulation to be moist. Possible causes include condensation from warm room air leaks directly into the machine or leaks in the duct's vapor barrier wrap. It is suggested that insulated flex-duct used for cold-climate air-to-air heat exchangers be appropriately rated and properly installed to handle extremely cold temperatures.

TEMPERATURE EXCESS AND JACKET GAINS

The analyst noted that "temperature excess," defined as the rise in temperature of the supply air minus the drop in temperature of the exhaust air,

of about 10°F was typical, suggesting some cold-air duct "pre-heat" and jacket gains could be occurring.

Measurements taken at the time of a site visit indicated that the real temperature excess may be somewhat less, but that, indeed, heat gains through ductwork, the jacket of the machine and from fan motors were measured to be much higher than conventional calculations would suggest.

FILTER NOTES

At several times during January 1985, the project analyst noted that both intake and exhaust temperatures at the Great Falls sites went into the 70°F and higher range, which was higher than any of the indoor temperature sensors. It was suspected that filters on the incoming air ports on the exterior of the houses may have frozen due to a local high-humidity weather condition, and that the high temperatures were caused by fan heat. This unusual condition happened several times. It was suggested that filtering incoming air, while necessary to screen insects and dust in warmer weather, may make for some problems during extreme winter conditions. Occupants may wish to simply remove these filters during the coldest winter weather, if separate animal screens are provided.

During site visits, filters were checked for debris. At one site, soil was found on the exterior filter indicating that action may be needed to further isolate the intake port from the ground. In addition, one builder hadn't cleaned the filters after construction, so construction dirt and dust was apparent. The manufacturer recommends a monthly inspection and cleaning of all filters. This is a minor task if the filters can be easily reached. In one installation, however, an exhaust filter is difficult to reach, meaning that some alteration of the installation may be desirable.

CONTROL NOTES

Site visits have indicated that speed controllers are inconsistent in behavior from site to site on these machines. For instance, one speed controller shows a sharp speed change from "high" to "low" speed, while another shows very little change. In another case, a speed control change turns both fans "off," yet the fans continue to cycle and heat up.

In one case, the occupants had the dehumidistat set so low that the machine was operating at high speed "override" at all times, making it appear that the other auxiliary switches didn't work. The speed controller was found to work as expected once the dehumidistat was properly set.

As was noted earlier, the defrost system provides inadequate control during very cold weather, which leads to high-frequency cycling. This situation may be substantially altered with the addition of the manufacturer's retrofit kit, but this wasn't possible during the initial monitoring period.

NOTES ON AIR FLOWS INSIDE THE HOUSES

Site visits and measurements indicate that undercutting interior doors to allow air return from bedrooms is an effective step, provided the builder considers a carpet height allowance. Measurements indicated substantial air flows at doors undercut 1/2" to 1".

Preliminary analysis of the data indicates that a central ventilation system designed in this fashion may indeed mix air such that heat from solar gains on the south rooms gets distributed over a period of time to the rest of the house.

OCCUPANT REACTION AND ASSESSMENTS

Occupant reaction to the systems has generally been positive at all three sites. The machines run quietly at all sites; so quiet, in fact, that one occupant reported that in the early weeks of occupancy, he would occasionally awake at night and couldn't hear the machine. Thinking it was off, he would check it to find it running. At Site 3, however, the sound of rapid defrost cycling was noticed by the occupant at night during very cold weather. This occupant opted to shut off the machine at night rather than manually defrost it. The other two occupant families opted to manually defrost the machine as necessary and possible.

At Sites 1 and 2, the occupants reported that they rarely opened windows and doors in cold weather for any reason and relied on the ventilation system completely. At Site 3, however, the occupants have mentioned a strong preference for higher-than-normal indoor moisture levels. The occupants have chosen to continue to vent the clothes dryer to the indoors, and they seem to like the occasionally higher humidity levels. In addition, these occupants operate the house at higher temperatures than Sites 1 and 2, and solar gains occasionally overheat the living/dining area. Their response is to open windows and doors to cool the house. Throughout the monitoring period, (Jan.-March 1985) Site 3 turned off the heat exchanger a number of times, and reported that doors and windows were opened frequently to cool the house.

MOISTURE LEVELS AND SUBJECTIVE ASSESSMENT OF VENTILATION

Indoor relative humidity (RH) measurements indicate that moisture is being controlled in these houses. At Sites 1 and 2, RH in the living area (based on a series of one-time measurements) is in the 24-36 percent range, and RH in the basements ranges from 32-45. Wintertime measurement at Site 3 was slightly higher: 37 percent upstairs and 40 percent in the basement. However, at Site 3, much higher RH levels were measured in March in the kitchen while cooking was going on (63 percent), and surely RH is higher when clothes are dried. However, no moisture-related symptoms or problems have been reported at Site 3 or at any of the other sites. Continuous RH measurements at all sites will be needed before final conclusions may be drawn.

During site visits during very cold weather, subjective assessments of ventilation effectiveness were made, and attendees at public open houses were occasionally asked for their perceptions.

At Site 1, ventilation seemed to be very effective. People smoked in the house most of the day (sometimes several people smoked simultaneously), yet new arrivals said they could not detect that tobacco had been smoked in the house. The occupant reported that his friends frequently smoke during their visits and that the ventilation system seems to remove the smoke so fast that the usually lingering odor of smoke (from contamination of carpets and furnishings) doesn't happen in this house. The occupant reports using the over-ride auxiliary switches whenever greatest ventilation is required or desired, and typically ran the unit continuously during the Jan.- March period.

At Site 2, an in-line damper that allows supply air to be directed to the upstairs or basement was omitted by the builder. Because the occupants rarely use the basement, it was advised that the damper be installed; once installed, air flows to the upstairs

increased. Ventilation seemed quite effective at this house, as well.

At Site 3, ventilation was somewhat affected by outdoor pollution: many of the occupant's neighbors burn wood for heat. At NCAT's first visit to the site in November 1984, the heat exchanger was off. When we turned it on, we strongly smelled woodsmoke, which, at first, we mistook for a fire. The occupant reported that, at times, they left the machine off to avoid the woodsmoke. More effective filters or an electrostatic air cleaning system might be called for at this site, if outdoor pollution from woodsmoke is to be avoided. Otherwise, ventilation seems effective at this site, when the occupants use the machine. These occupants said that indoor RH of 40 percent seemed "too dry;" they seem to prefer low ventilation levels and higher humidity levels. They also achieve extra ventilation by the frequent opening of windows.

Cooler supply air in the 41°F - 50°F temperature range during sub-zero weather was not reported as a problem by any of the occupants. Supply air is, the these houses, moving at a slow speed and registers are located high up over doorways. At least one noted that, in a conventional house, "ventilation air" would be coming in through cracks and leaks at a bone-chilling -10° F to -20° F. Air mixing seems, on a subjective basis, better when supply air temperatures are at their coolest. When supply air temperatures begin approximating room temperatures (at ambient temperatures of about 30° F and above) a marked decrease in perceptable air flows was apparent. Detailed measurements are needed to validate this perception.

CONCLUSIONS

Occupants in three virtually identical houses with very similar ventilation systems have reported few problems with their systems, and, have, for the most part achieved a new level of control over their home environments.

As opposed to a simple, exhaust-only ventilation system without heat recovery, the air-to-air heat exchangers provide for dehumidification, as well as more livable wintertime indoor RH levels, pre-heat of ventilation air and energy savings from heat recovery. In the cold climate of Great Falls, controlled ventilation of this type with heat recovery allows for a very tight building envelope that makes for a high degree of wintertime comfort. Controlled ventilation of this type may also lead to enhanced ventilation levels and control compared to a conventional house.

Because of the many roles assigned to the central ventilation system, it is difficult to fully assign economic benefits to the use of this new technology. Frequently, only heat recovery is considered in economic analysis, while the possible benefits of humidity control and occupant health and comfort are rarely quantified.

On a simple operational level, at $0.04 per kilowatt hour (kwh), the cost of operating these units on a year-round continuous basis could be roughly $64 (for 1600 kwh annually) but its net savings could be roughly $116 annually (estimated 2900 kwh). Simple "payback" analysis for the entire ventilation system is probably not appropriate because other values of the system are not easily quantified. More detailed monitoring and analysis of these systems over the course of this project could provide a much more complete picture in this regard.

This preliminary report on the Montana Superinsulation Project's initial

experience with air-to-air heat exchangers represents a snap-shot in time in the evolution of this technology. Five years ago, it was hard to find a residential-scale heat exchanger. Before the project's first winter had passed, the machine installed in these houses was being supplanted by a potentially improved design, which has addressed the problems of cold-weather defrost performance and other issues.

A highly detailed house plan that clearly shows the installation of the ventilation system is a first step, which can allow even an inexperienced, owner-builder to adequately construct the system. The difficulty for these project homeowners may relate to the future; service and dealer networks for heat exchangers are not well established in Montana. Until the industry expands (and more service people are trained), system design, trouble-shooting and initial air-flow balancing will continue to be difficult services to get in most parts of Eastern Montana.

The successful use of this technology in the Northwest on a large scale depends on further research, development and professional education to provide instruction on ventilation system design, installer and dealer training, as well as banker, builder, Realtor and buyer information. The bulk of the responsibility falls to the manufacturers in all regards.

Government research efforts need expansion, in order verify and document performance, and to set reasonable guidelines for all parties involved. In addition, the climate zones to which this technology might best be suited is a question that deserves further consideration.

ACKNOWLEDGEMENTS

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APPENDIX E:

MEASURED PERFORMANCE OF THREE SUPERINSULATED HOMES IN MONTANA

MEASURED PERFORMANCE OF THREE SUPERINSULATED HOMES IN MONTANA

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ABSTRACT

The State of Montana, Department of Natural Resources and Conservation, Energy Division is monitoring five superinsulated homes in Eastern Montana. At each home, seventeen channels of data are recorded hourly. Data summarized on a daily and monthly basis is available from the National Center for Appropriate Technology in Butte, MT. Of the five homes, three are occupied. These three are all located in Great Falls, MT. This paper summarizes the data from these occupied homes for the first three months of 1985. An overview of the project is given in [1].

INTRODUCTION

The homes are two story, with the lower story being a full basement. The floor area is roughly 2400 square feet. Each home has a VanEE R-200 air-to-air heat exchanger. Space heat is provided by electric baseboard convectors. Each room has a separate thermostat. Site 1 has a hot tub. Details of the construction features of the homes are given in [2].

The homes were built in the late summer and fall of 1984. The dates of occupancy were Dec. 23 for Site 1, Nov. 17 for Site 2, and Oct. 1 for Site 3. Complete monitored data for all three sites is available after Dec. 23.

The results of occupant interviews are given in [3]. Blower door air tightness test results are given in [4]. Field heat exchanger measurements are described in [5]. The monitoring system is described in [6]. In addition, several engineering site visits have been made for the purpose of spot measurements [7,8]. An analysis of the passive solar features of Site 2 is given in [9]. A graphical presentation of much of the actual hourly data for the first six weeks of the monitoring period is given in [10].

The seventeen channels of data are: indoor temperatures in three bedrooms, the kitchen-living-dining room, and one room in the basement, ambient temperature, south vertical solar radiation, total electrical use, space heat upstairs, space heat downstairs, water heater, and dryer. In addition, we monitor the heat exchanger supply air temperature immediately downstream of the unit, the exhaust air temperature immediately downstream of the unit, and the percent of each hour in which the supply and exhaust fans operate.

PERFORMANCE RESULTS

The measured performance of the three homes for the first three months of 1985 are presented in the tables and graphs. Electrical consumption by end use for the first quarter is summarized in Table

1. The concomitant indoor temperatures, weather conditions, and hot water use are summarized in Table 2. A more detailed graphical presentation is given in Figs. 1-12. Figs. 1 and 2 show weather conditions by day of year and time of day. Figs. 3 and 4 show indoor temperatures by day of year and time of day. Figs. 5 and 6 show space heat by day of year and time of day. Fig. 7 shows hot water use by day of year, and Fig. 8 shows "other" by day of year. Fig. 9 shows the contribution of each end use to overall electrical consumption by time of day. Fig. 11 shows the percent of each day that the heat exchanger supply fan is off, and Fig. 12 shows the heat exchanger excess temperature by day of year. The captions make these figures self-explanatory. The figures contain a large amount of information and will repay careful study and cross comparison.

One aspect of electical use of interest to utilities is peak demand. The project homes had the following peaks:

	Total			Space Heat		
	KW	HR	DAY	KW	HR	DAY
Site 1	11.3	11am	45	4.1	11am	20
Site 2	8.0	10am	29	4.4	6am	20
Site 3	13.0	9am	40	4.9	12am	32

DAILY SPACE HEAT AND TEMPERATURES

Fig. 10 shows daily space heat plotted against difference between daily average indoor temperature and daily average ambient temperature. The plots show the expected tendency for larger space heat loads to be associated with larger temperature differences. There are several points worth noting: 1) there is a lot of scatter, 2) the slope of the left half of the data is much greater than that of the right half, and 3) there is a tendency for the points to occur in clumps. The clumps are associated with consecutive days when operating conditions were similar. The plots suggest that straight line fits to this data (where the slope coefficient is interpreted as the house UA and the x-intercept as a balance point temperature difference) will yield unstable coefficents. Also, in this case, the basement heat loss tends to appear in the intercept rather than the slope. Simple regression techniques for weather adjustment are not likely to work well for occupied, superinsulated homes with basements. In a warmer climate, the situation would be much worse.

SUNDAY SIMULATION RESULTS

In order to make a projection of annual space heat requirements, we adjusted the input parameters of the SUNDAY daily simulation model to match the January space heat use averaged across the three homes. The inputs used were:

Thermostat setpoint	65 F
Building UA	263 BTU/F-h
Heat Storage	6000 BTU/F
Internal Gains	4500 BTU/h
South Glass	54.8 Sqft
North Glass	8.8 Sqft
East Glass	14.3 Sqft
West Glass	23.1 Sqft
Shade Factor	.7

The results are shown in Table 3. The average space heat for the homes for the first 3 months agrees with the measured value within 5 percent. The predicted annual space heat is 4500 KWH. With the same assumptions, the space heat in Seattle would have been 1200 KWH. With the thermostat setting increased to 72 F (similar to Site 3), annual space heat in Great Falls is 6700 KWH.

It should be emphasized that these space heat projections are the result of an empirical model. The combination of parameters used gives reasonable agreement with the data for the second half of the heating season (and presumably, over the first half as well). This does not imply that the parameters (UA, setpoint, gains, etc.) are correct.

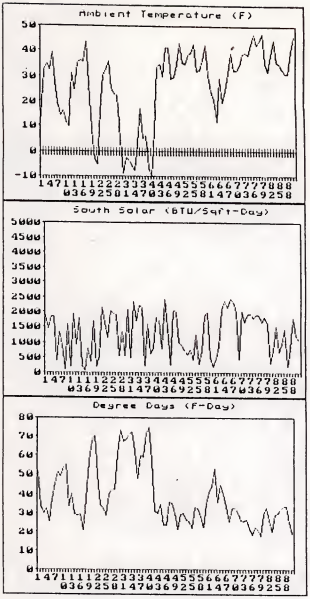

Fig. 1 GREAT FALLS WEATHER CONDITIONS FOR 1985 BY DAY OF YEAR AT SITE 3. The top panel shows mean daily ambient temperatures, and the lower panel shows base 65 F heating degree days. Notice that a large percentage of degree days and the consequent heating load occur during a few well defined cold snaps. The onset and termination of these cold spells is very sudden with temperatures changing 45 F within 24 hours. The middle panel shows total daily south vertical solar radiation. The weather is relatively sunny, but there is a large day to day variation.

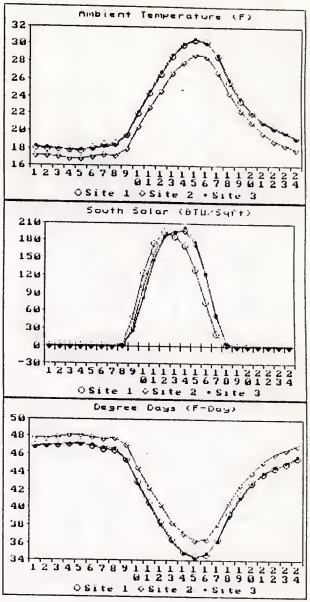

Fig. 2 GREAT FALLS WEATHER CONDITIONS BY TIME OF DAY FOR JAN-FEB OF 1985. The upper panel shows mean ambient temperatures at the three sites, and the lower panel shows heating degrees or the temperature difference between 65 F and ambient. Note that Site 2, which is on a hill, is slightly colder. The typical variation from maximum to minimum of 13 F is due to solar radiation, which is shown in the middle panel. The solar at Site 1, which faces 30 degrees east of south, shows a different pattern than that for the other sites, which face due south.

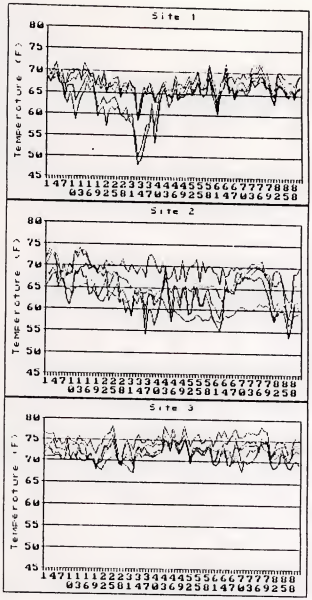

Fig. 3 INDOOR TEMPERATURES FOR 1985 BY DAY OF YEAR. Each panel shows the daily average for each of the 5 measured indoor temperatures at a site. At Site 1, the heat in the two north bedrooms was turned off from day 10 through 44. At Site 2, the basement heat was progressively reduced, and the two south bedrooms were only partially heated. All rooms at Site 3 were maintained consistently at similar temperatures. At all 3 sites, the basement temperature is the smoothest and the living-dining room temperature is the highest.

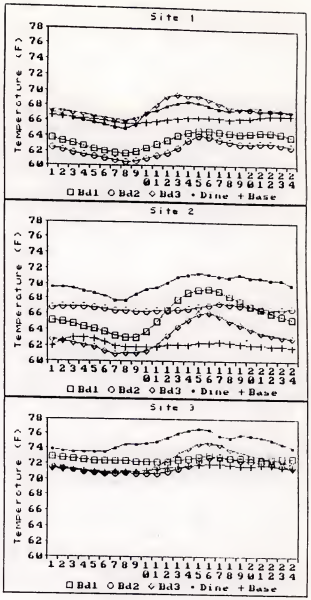

Fig. 4 INDOOR TEMPERATURES BY TIME OF DAY FOR JAN-FEB OF 1985. Each panel shows the mean for each of the 5 measured indoor temperatures at a site. The lowered temperatures of the two north bedrooms at Site 1 are evident. At Site 2, bedroom 3 and the living room are the rooms of primary occupancy, while the south bedrooms show solar induced temperature swings, and the basement is kept cool. At Site 3, room temperatures are kept even. At all 3 sites, the living-dining room tends to be warmer than the others, and the basement has very little swing.

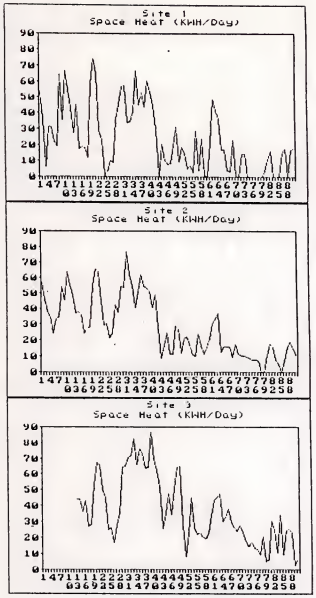

Fig. 5 SPACE HEAT FOR 1985 BY DAY OF YEAR. The panels show total daily space heat for each of the sites. The space heat at all 3 sites tends to track the degree days shown in Fig. 1 in a very rough way. The generally lower thermostat settings at Site 1 allow the heat to approach zero more often. The higher thermostat settings at Site 3 are also evident. All 3 sites show the marked drop in degree days occurring after day 44. Note that the range from near zero to typical maximum values can occur within a day or two.

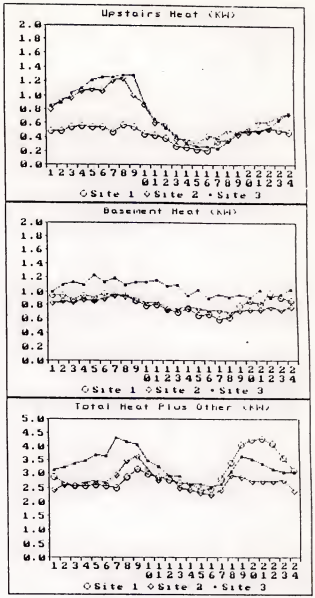

Fig. 6 SPACE HEAT BY TIME OF DAY FOR JAN-FEB OF 1985. The top panel shows mean upstairs space heat for the three sites. Sites 2 and 3 show the expected maximum around 8 to 9 am. Ambient temperature is then at its minimum and the heat stored in the structure has been depleted. Site 1 does not show this pattern, because the indoor temperatures are allowed to drop at night. The middle panel shows basement heat, which tends to be much more constant at all sites. The lower panel shows the sum of space heat and other, which is a better measure of the total electrical heat input to the home.

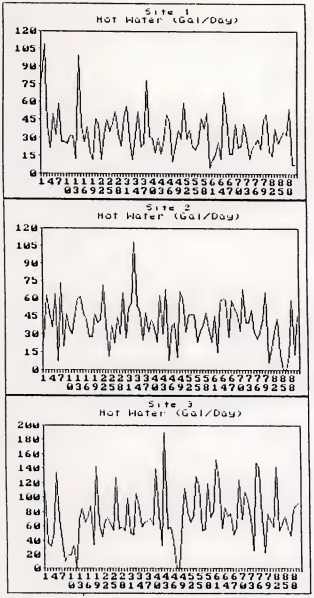

Fig. 7 **HOT WATER USE FOR 1985 BY DAY OF YEAR.** Each panel shows the total gallons of hot water used for a site. The water use is very irregular from one day to the next, ranging from zero to 200 gallons. The spikes are days when laundry is done. The dryer use is even more irregular and spiky with peaks on the same days. Hot water use is the most sensitive indicator of occupancy. There are several absences of 2 to 4 days visible and a number of days of very low use. The vacancy around day 85 at Site 2 is also visible in some of the other figures.

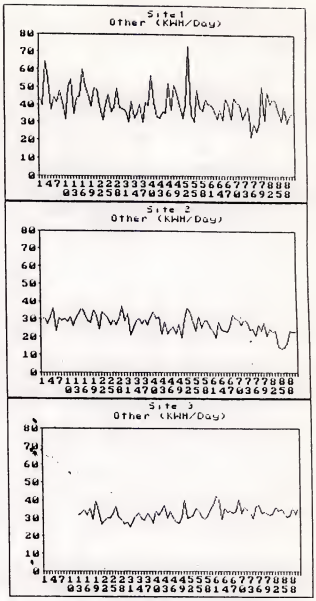

Fig. 8 **"OTHER" USE FOR 1985 BY DAY OF YEAR.** The panels show total KWH used for "other", defined as the total electric use minus space heat, water heat, and dryer. It represents a lighting and small appliance base load. Sites 2 and 3 show typical patterns of variation about a well defined average value. The higher general level and the irregular large spikes shown at Site 1 are due to use of the hot tub. Notice that the "other" tends to remain rather steady, even when the homes are empty (compare with Fig. 7).

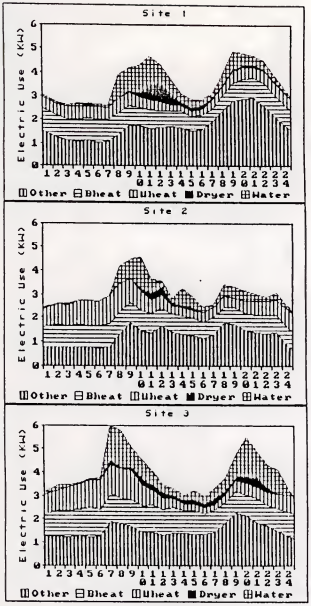

Fig. 9 END USE PROFILE BY TIME OF DAY FOR JAN-FEB 1985. The panels show the contribution of each measured end use to total electrical consumption for each site. The "other" profile for Site 3 shows a morning and evening peak with midday levels similar to late night reflecting lack of daytime occupancy. The Site 2 profile of "other" shows a pattern typical of 24 hour occupancy. The large evening peak of "other" at Site 1 is due to hot tub use. At all 3 sites water heater use is the main contributor to daily consumption peaks.

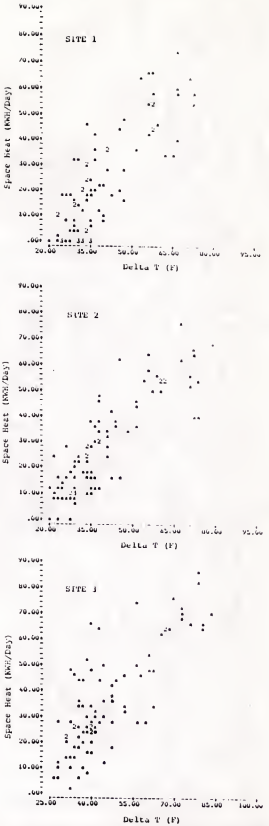

Fig. 10 DAILY SPACE HEAT VERSUS INDOOR TO AMBIENT TEMPERATURE DIFFERENCE.

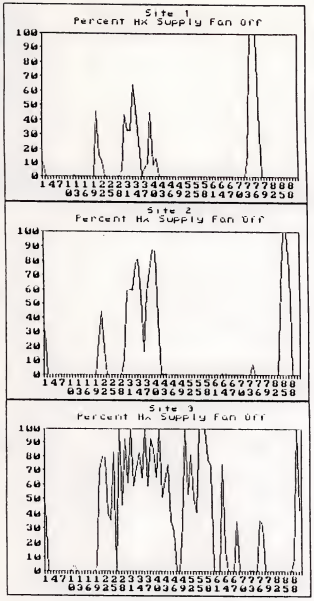

Fig. 11 HEAT EXCHANGER SUPPLY AIR FAN STATUS FOR 1985 BY DAY OF YEAR. The panels show the percent of the day during which the heat exchanger supply fan was off. The defrost mechanism of the exchanger operates by turning off the supply fan, while the exhaust fan pumps warm air through the core. The patterns for Sites 1 and 2 show typical operation with extensive defrost mode during the cold snaps. Reduced defrost mode at Site 1 is due to manual defrost by occupant. Site 3 unit was turned off frequently by occupant. Units were turned off at all sites for several days in March.

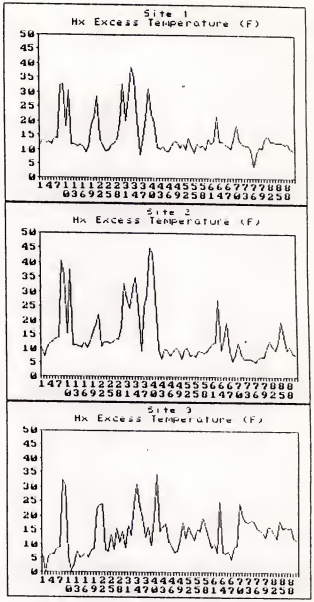

Fig. 12 HEAT EXCHANGER TEMPERATURE EXCESS FOR 1985 BY DAY OF YEAR. The panels show the excess temperature for the heat exchangers, defined as the rise in temperature of the supply air minus the drop in temperature of the exhaust air. Sites 1 and 2 show a typical pattern with a base of about 10 F. This is due to a combination of fan heat, duct preheat, jacket gains, and condensation heat transfer. The peaks after day 12 reflect exhaust icing and defrost mode. The peaks on days 8,9, and 11 are due to icing of the inlet filter by freezing fog. Defrost mode at Site 3 prevented the icing on day 11.

TABLE 1 Summary of Electrical Use for the First Three Months of 1985 (KWH)

	Site 1	Site 2	Site 3	Avg
January				
Upstairs Heat	325	550	694	523
Downstairs Heat	750	773	781	768
Total Heat	1075	1323	1474	1291
Dryer	97	28	83	69
Water Heater	359	235	404	333
Other	1362	945	967	1091
Total Appliance	1817	1208	1454	1493
Grand Total	2892	2530	2929	2784
February				
Upstairs Heat	305	482	341	376
Downstairs Heat	415	353	986	585
Total Heat	720	835	1327	961
Dryer	74	31	88	64
Water Heater	250	224	446	307
Other	1130	771	887	929
Total Appliance	1455	1027	1421	1301
Grand Total	2174	1862	2747	2261
March				
Upstairs Heat	137	331	231	233
Downstairs Heat	204	74	479	252
Total Heat	341	405	710	485
Dryer	62	25	99	62
Water Heater	221	213	527	320
Other	1137	735	1068	980
Total Appliance	1421	973	1695	1363
Grand Total	1762	1378	2404	1848
Three Month Total				
Upstairs Heat	767	1363	1266	1132
Downstairs Heat	1369	1200	2246	1605
Total Heat	2136	2563	3511	2737
Dryer	233	84	270	196
Water Heater	830	672	1377	960
Other	3629	2451	2922	3001
Total Appliance	4693	3208	4570	4157
Grand Total	6828	5770	8080	6893

TABLE 2 Monthly Average House Temperatures, Weather Conditions, and Hot Water Consumption for First Three Months of 1985.

	Site 1	Site 2	Site 3	Average
January				
Temperatures (F)				
Bedroom 1	64.47	68.54	72.18	68.40
Bedroom 2	63.08	68.58	71.13	67.60
Bedroom 3	68.47	64.76	72.05	68.43
Dining Room	68.20	70.65	74.47	71.11
Basement	67.40	64.23	69.85	67.16
Average House	66.33	67.35	71.94	68.54
Ambient	21.52	20.20	21.42	21.05
Average Delta	44.81	47.15	50.52	47.49
Heating Degree Days (F-Days)	1348	1389	1351	1363
Solar Radiation (Btu/Sqft-Day)	1126	1203	1161	1163
Hot Water (Gal/day)	40.4	41.7	61.6	47.9
February				
Temperatures (F)				
Bedroom 1	62.59	63.19	73.05	66.28
Bedroom 2	61.56	64.74	72.11	66.14
Bedroom 3	66.90	61.51	72.76	67.06
Dining Room	66.04	69.30	75.39	70.24
Basement	65.16	60.00	73.23	66.13
Average House	64.45	63.75	73.31	67.17
Ambient	23.37	21.90	23.55	22.94
Average Delta	41.08	41.85	49.76	44.23
Heating Degree Days (F-Days)	1166	1207	1161	1178
Solar Radiation (Btu/Sqft-Day)	1179	1268	1266	1238
Hot Water (Gal/day)	33.1	42.9	75.0	50.3
March				
Temperatures (F)				
Bedroom 1	66.08	62.71	72.25	67.01
Bedroom 2	66.33	66.45	71.40	68.06
Bedroom 3	68.98	63.90	73.29	68.72
Dining Room	67.58	68.19	75.51	70.43
Basement	66.29	59.29	71.87	65.82
Average House	67.05	64.11	72.68	67.95
Ambient	34.29	33.12	34.69	34.03
Average Delta	32.76	30.99	37.99	33.91
Heating Degree Days (F-Days)	952	988	940	960
Solar Radiation (Btu/Sqft-Day)	1348	1501	1443	1431
Hot Water (Gal/day)	27.5	36.0	82.0	48.5
Three Month Averages				
Temperatures (F)				
Bedroom 1	64.44	64.87	72.47	67.26
Bedroom 2	63.73	66.65	71.53	67.30
Bedroom 3	68.16	63.45	72.70	68.10
Dining Room	67.31	69.38	75.11	70.60
Basement	66.32	61.21	71.60	66.38
Average House	65.99	65.11	72.62	67.91
Ambient	26.49	25.18	26.65	26.11
Average Delta	39.50	39.93	45.97	41.80
Total Degree Days (F-Days)	3466	3584	3452	3501
Solar Radiation (Btu/Sqft-Day)	1219	1326	1291	1279
Hot Water (Gal/day)	33.7	40.1	72.8	48.9

TABLE 3 Comparison of Monitored Space Heat with Simulation Results

	Space Heat (KWH/Month)					Degree Days (Base 65)	
	Site 1	Site 2	Site 3	Avg	SUNDAY	Site Average	SUNDAY
Jan	1075	1323	1474	1291	1251	1363	1331
Feb	720	835	1327	961	821	1178	1068
Mar	341	405	710	485	548	960	1016
Total	2136	2563	3511	2737	2620	3501	3415
Annual Projection					4509		7598

TABLE 4 Water Heater Standby Loss Analysis Results

Site	Standby Loss (KWH/day)	Temperatures(F) Apparent Tank	Average Bsmnt	Apparent Tank UA (W/F)	Tank Specifications and Insulation Measures
1	1.38 ± 10%	141.6	66.6	0.77	American Appl EXR52-1D,52 gal, 2" bottom board
	0.98 ± 12%	130.4	66.1	0.64	Same as above with lower thermostat setting.
2	0.45 ± 29%	110.5	61.2	0.38	Bradford-White M2-50S5,50 gal, 1 1/2" tank wrap, 4" bottom board, 3 1/2' insulation on hot water pipe.
3	1.51 ± 8%	114.8	71.6	1.46	Tank type unknown, 1" tank wrap, 4" bottom board, 5' insulation on hot water pipe.
4	1.77 ± 3%	146.0	58.6	0.84	Mor-Flo EXR-52,52 gal, 3" bottom board, 5' insulation on hot and cold water pipe.
	1.18 ± 5%	146.0	58.6	0.57	Same as above plus R-19 tank wrap.

Tanks at Sites 1 and 4 have a GAMA [13] standby rating of 0.6% per hour, which is equivalent to a tank heat loss rate of 0.75 W/F. The same tank was laboratory tested by the Bonneville Power Administration, with the following results [14]:

0.9263	Tank only
0.8127	Tank w/ bottom board
0.6475	Tank w/ bottom board and R-11 tank wrap.

PROJECTED ANNUAL ELECTRIC USE

Using the SUNDAY space heat estimate, and multiplying the measured first quarter data for other end uses by 4, provides the following tentative annual electric end use projection (assuming the price of electricity is $0.04/KWH):

	KWH	$
Space Heat	4500	180
Water Heat	3800	152
Dryer	800	32
Other	12000	480
Total	21100	844

The hot tub at Site 1 will use roughly 3000 KWH/Y. Removing this use from the "Other" will reduce it by about 1000 KWH/Y. The heat exchangers will use roughly 1600 KWH/Y, if operated continuously. If we assume that .45 air changes per hour are required (with or without heat recovery), the winter heat savings from the heat exchanger is about 3700 KWH, while the fans use about 800 KWH. The net winter savings from the heat exchanger are roughly 2900 KWH, about enough to pay for the operation of a hot tub. These are back-of-the-envelope calculations, meant only to provide perspective. More measurement and analysis will be required to improve them.

COMPARISON WITH EUGENE DATA

The Eugene Water and Electric Board has submetered 12 "Efficient Homes" and 14 "Conventional Homes" since 1978. Four years of this data are summarized in [11]. It is of interest to compare the 1985 space heat results [12] with those from this project. Since the homes are all of different sizes, the space heat use was converted to KWH per square foot of floor area. January in Eugene has about 900 heating degree days, while March in Great Falls had 940 degree days. The comparison is the average of all occupied Eugene homes in each category for the month of January with the average of the Montana homes for the month of March. About half the Eugene Efficient homes are heated with heat pumps, and a few of each category use wood heat.

	KWH/Sqft	Ratio
Eugene Conventional	1.59	7.95
Eugene Efficient	.70	3.48
Montana Project	.20	1.00

The comparison (rough as it is) suggests the Montana homes are significantly more efficient than the Eugene Efficient homes. For comparison the January space heat for Site 3 (which has all 2400 square feet heated to 71 F) was 0.61 KWH/Sqft with 1351 degree days.

WATER HEATER STANDBY LOSSES

All of the Montana homes have some conservation measures to reduce water heater standby losses. These include energy efficient tanks with R-value ratings greater than R-16 Sqft-F-h/BTU, fiberglass jackets over the tanks, foam bottom boards and pipe insulation. We used daily data to estimate the standby losses. The daily total water heat energy was regressed on daily total gallons used. The intercept of this line is the energy used when gallons are zero (i.e., standby losses).

The slope of this line can be converted to an apparent cold water to tank temperature difference. This temperature difference was added to site measured cold water temperatures of 36-38 F to produce an apparent tank temperature. The mean basement temperature was subtracted from the apparent tank temperature to provide an estimated delta to basement air. This delta was divided into the regression estimated standby loss rate to provide an estimated tank UA.

The results of the analysis are given in Table 4. The regressions for Site 1 indicated a change in tank setpoint. This was independently verified, so we

divided the data into two time periods with separate fits. The regressions for Site 4 indicated a step change in standby loss. We independently verified that an R-19 jacket had been added at that time. This again led to two separate fits, one with jacket and one without. By coincidence, the tanks used at Sites 1 and 4 were identical to a tank on which the Bonneville Power had conducted extensive laboratory standby tests.

The standby loss at Site 4, which is unoccupied, was very well determined. The inferred tank UA also shows reasonable agreement with the laboratory measurements, both with and without the jacket. The standby loss at Site 2 was poorly determined and abnormally low. This should be investigated further. The estimated standby losses are quite small at all 4 sites, ranging from about 150 to 550 KWH/Y. This can be compared with an average standby of 1100 KHW/Y predicted by BPA and a measured average of 1700 KWH/Y found in a recent study of heat pump water heaters [15].

ACKNOWLEDGEMENTS

This paper reports on work funded in part by the Montana Department of Natural Resources and Conservation Energy Division. The authors gratefully acknowledge the occupants' cooperation, which makes the project possible. Michael Kennedy of Ecotope developed the software which interrogates the data loggers and has archived the weekly data.

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APPENDIX F:

MEASURED PERFORMANCE OF SUPERINSULATED HOMES IN MONTANA: SECOND REPORT

MEASURED PERFORMANCE OF SUPERINSULATED HOMES IN MONTANA: SECOND REPORT

Larry Palmiter and Jim Hanford
Ecotope, Incorporated

ABSTRACT

Five all-electric superinsulated homes are being monitored in Eastern Montana. For each home, over a year's worth of hourly data on seventeen channels has been collected.

The energy performance of these homes is consistent with expectations, and can be summarized as follows:

1. Average annual 1985 space heat for three occupied homes in Great Falls was 5207 kWh (2.17 kWh/Sqft) in a year with 8218 base 65 degree days. The heating system provided about 34% of the total heating load, while internal gains provided about 53% and passive solar gains provided about 13%.

2. Space heat consumption varies by almost 2 to 1 between sites due to different levels of internal and solar gains, and different thermostat settings.

3. Average annual 1985 electric use of the three occupied homes was 20,077 kWh, of which 26% was space heat, 17% was water heat, 4% was dryer, and 53% was "Other" which includes everything else.

INTRODUCTION

Recent approaches to low-energy housing, especially in the Pacific Northwest, favor high levels of insulation in combination with predominantly south facing glass. In these superinsulated homes, internal and solar gains are expected to offset much of the space heating requirements. To evaluate actual field performance of these structures and to assess occupant satisfaction, five superinsulated homes are being monitored in eastern Montana. This paper is the second in a series which summarize the measured data and performance of these homes. [1]

The five homes were built in the late summer and fall of 1984 and have been monitored since January of 1985. Three sites have been continuously occupied, one has had short unoccupied periods, and one is an unoccupied control unit. The homes are virtually identical two story structures with full basements, with a total floor area of approximately 2400 square feet. Each is equipped with electric baseboard heating units with separate thermostats in each room and air-to-air heat exchangers.

Seventeen channels of data are recorded hourly. At each site, ambient air temperature and south vertical solar radiation are measured along with five indoor air temperatures. Monitored electricity consumption includes upstairs heat, basement heat, water heat, dryer consumption, and a house total. On the air-to-air heat exchanger the supply and exhaust air temperatures are measured along with the percent on-time of the supply and exhaust fans. Data summarized on a daily and monthly basis is available from the National Center for Appropriate Technology in Butte, Montana.

DESCRIPTION OF HOMES AND OCCUPANTS

The five homes were all built according to the same set of plans with some deviations. Insulation in the building components includes R-50 ceilings, R-40 walls on the north, east, and west, R-26 walls on the south, R-12 doors, R-19 on the basement walls, and R-8 under the basement slab. Windows are either triple glazed or low-E double, with 35.7 square feet on the south wall and 13.8 square feet on each of the north, east, and west walls. There is also a continuous polyethylene air-vapor barrier and mechanical ventilation with an air-to-air heat exchanger.

Deviations from the plan do exist. Sites 1 and 5 are oriented up to 30 degrees from true south. Sites 2 and 3 use standard double glazing on some of the windows, and window areas and orientations were altered on every home. Sites 4 and 5 have attached garages, and Site 1 has a hot tub in the basement. Sites 1, 2, and 3 are located in Great Falls, Site 4 is in Lewistown, and Site 5 is in Billings.

Site 1 is occupied by a small working family. A retired couple lives at Site 2 and they are typically home during the day. Site 3 is a family of four including two working parents so the home is empty during most of the daylight hours. Several renters have occupied Site 4, and each has operated the home in a different manner. Site 5 was unoccupied until March of 1986.

PERFORMANCE RESULTS

The measured performance of the homes is presented in the tables and graphs. Annual data summaries for the three occupied homes in Great Falls during the year 1985 are in Table 1. Space heat for the year averaged 5207 kWh, or about one quarter of the total house consumption. The end use Other averaged 10,569 kWh for the three sites, representing 53 percent of the total load. Note that while ambient temperature and solar radiation varied little between the sites, there is a difference of almost 2 to 1 in the annual space heating consumption. A graphical depiction of the 1985 electrical consumption at the three sites is in Figure 1 and the weather data and upstairs temperatures for the same period are shown in Figure 2. The data for the calendar year has been folded and is represented as July through June to better see the space heating data. Note that the heating season is

confined to only about five months, November through March. A large proportion of the space heating consumption occurs during short periods of continued cold.

Table 2 gives monthly electricity consumption for the five sites during the 1985-86 heating season to date, November through February. There was a small amount of heating in October, but after November 1 heating has occurred essentially uninterrupted. It also shows the interior temperatures, hot water consumption, and weather conditions for the same period. Daily space heat, indoor temperatures, and base 65 F degree days for the period are depicted graphically in Figure 3. Much of the performance variation in space heating between the homes can be explained by comparing the temperatures and Other consumption found in the measured data. It is also of interest to compare data from the occupied sites with that from Site 5, which is unoccupied. Figure 4 shows average daily end-use profiles for each of the five homes during this period, which highlight the variation in the way the occupants operate their homes.

DIFFERENCES IN SPACE HEAT BETWEEN HOMES

A comparison between the three occupied Great Falls sites for the year 1985 shows almost a 2 to 1 difference in measured space heat consumption with almost identical weather conditions. For the 1985-86 heating season, sites show an even greater spread, especially when including unoccupied Site 5 in the comparison. There are several reasons for the difference.

One reason is the levels of internal gains. While space heat consumption is quite different, the sum of space heat and Other consumption is less different, and removes a good deal of the variation between homes.

Thermostat setpoints also contribute to house-to-house variation in space heat consumption. During the spring of 1985, the occupants at Sites 1 and 2 kept their homes much colder than those at Site 3, and their space heating consumption was much lower. Occupants at all sites except for Site 3 also tend to maintain different temperatures in the different rooms of the house, sometimes with temperature differentials of 10 to 15 F between rooms.

For instance, the basement at Site 2 was essentially unheated for most of spring 1985 and stayed about 6 F below the upstairs temperature. This tends to reduce the actual heated area by a factor of almost 2. However, in the fall of 1985, the basement was heated to temperatures consistent with the rest of the home.

SUNDAY SIMULATION RESULTS

In order to make a projection of annual space heat requirements in the early stages of the project, we adjusted the input parameters of the SUNDAY daily simulation model to match the January 1985 space heat use averaged across the three occupied homes. The inputs used were:

Thermostat Setpoint	65	F
Building UA	263	BTU/Sqft-F-h
Heat Storage	6000	BTU/F
Internal Gains	4500	BTU/h
South Glass	54.8	Sqft
North Glass	8.8	Sqft
East Glass	14.3	Sqft
West Glass	23.1	Sqft
Shade Factor	.7	

Predicted annual space heating energy was 4509 kWh using Great Falls TMY weather data, compared with the measured average of 5207 kWh for the three Great Falls sites. The TMY weather year has 7598 base 65 degree days compared with a measured 8218 averaged across sites.

Use of actual weather data with the same assumptions yielded a predicted annual space heating energy of 5253 kWh, within 0.8% of the measured result. However, deviations in single months reached as high as 400 kWh in November. This may be due to the presence of the basement, which loses much of its heat to the surrounding soil where temperature fluctuations lag those of ambient.

The simulations provided an estimate of the contributions of various heat sources toward meeting the overall thermal load:

Internal Gains	7999 kWh	53%
Heating System	5253 kWh	34%
Passive Solar	1991 kWh	13%
Total Heating	15243 kWh	100%

The simulation model also allows estimates of the sensitivity of annual space heat to changes in the parameters and climate. For the Great Falls climate and with no internal gains, the space heat load would increase to 12080 kWh and the solar contribution to 21%. About 42% of a reduction in annual internal gains will appear as an increase in space heat. A one degree F change in average thermostat setting will cause a 4% change in annual space heat. With the inputs listed above, space heat in Seattle, Washington would have been only 1200 kWh.

It should be emphasized that these space heat projections result from an empirical estimation of the model parameters. The combination of parameters used gives reasonable agreement with the monthly measured data for the three

homes occupied throughout the year. The predictions were also in agreement with the unoccupied control home. This does not imply that the parameters (UA, setpoint, gains, etc.) are correct.

The presence of multiple thermostats, leading to large room-to-room temperature variations, changes in thermostat settings over time, vacations and vacancies, variations in internal and solar gains across homes, between rooms, and over time, variations in the use and settings of the air-to-air heat exchangers, and the thermal flywheel effect of the basements combined with the concentration of space heat into short cold spells makes it difficult to predict space heat for individual homes or specific months.

ACKNOWLEDGEMENTS

This paper reports on work which was funded in part by the State of Montana, Department of Natural Resources and Conservation, Energy Division and managed by the National Center for Appropriate Technology in Butte, Montana. The authors gratefully acknowledge the cooperation of the occupants which makes the project possible. Michael Kennedy of Ecotope, Inc. developed the software for interrogation of the data loggers and has archived the weekly data.

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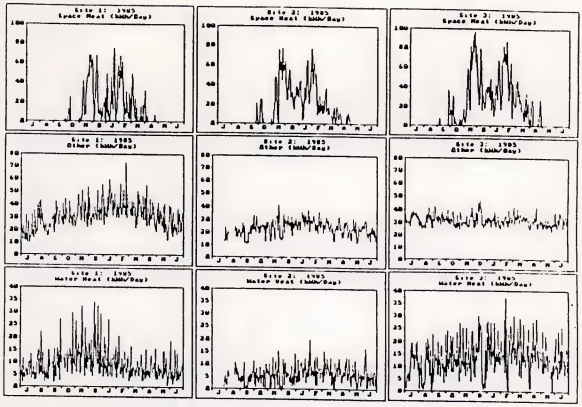

FIG. 1. DAILY ELECTRICAL END USE FOR 3 SITES IN GREAT FALLS DURING 1985.
The time scale in each plot has been arranged to run from July through June. The first row shows space heat usage. The bulk of space heat usage (81 to 87%) occurs during Nov. through Feb. The number of days with nonzero space heat ranged from 172 to 215. Much of the space heat was used during two prolonged cold snaps in Nov. and Feb. The second row shows the consumption of Other. The generally high level and spiky appearance of the Other for Site 1 reflects hot tub use. The strong seasonal variation may also be due to tub use. Site 3 shows a typical pattern while Site 2 shows seasonal variation. The bottom row shows water heat usage. This is the best indicator of occupancy. Vacations and weekend trips are evident at both Sites 2 and 3, while Site 3 shows typically greater water heat use on weekends due to clothes washing. Water heat shows a strong seasonal variation at all sites due to variation in mains temperature. Residuals from a fit of water heat KWH to Gallons were used to estimate a mains temperature variation of about 25 F peak to peak. Note the large day-to-day variation in water heat.

Table 1. 1985 Annual Data Summaries for Three Sites in Great Falls, MT

Electricity Consumption (kWh)	Site 1		Site 2		Site 3		Average	
Upstairs Heat	1579	8%	2389	15%	2770	11%	2246	11%
Basement Heat	2279	11%	2639	17%	3965	16%	2961	15%
Total Heat	3858	19%	5028	32%	6735	28%	5207	26%
Dryer	1226	6%	308	2%	903	4%	812	4%
Water	3436	17%	2150	13%	4882	20%	3489	17%
Other	11576	58%	8441	53%	11689	48%	10569	53%
Total Appliance	16238	81%	10899	68%	17474	72%	14870	74%
House Total	20096	100%	15927	100%	24209	100%	20077	100%
Hot Water Use (Gal/Day)	41.7		37.5		76.1		51.8	
Vertical Solar (Btu/Sqft-Day)	936		994		943		958	
Heating Degree Days (F-Day)	8101		8435		8117		8218	
Space Heating								
kWh/Sqft	1.61		2.10		2.81		2.17	
Btu/Sqft-Degree-Day	.68		.85		1.18		.90	

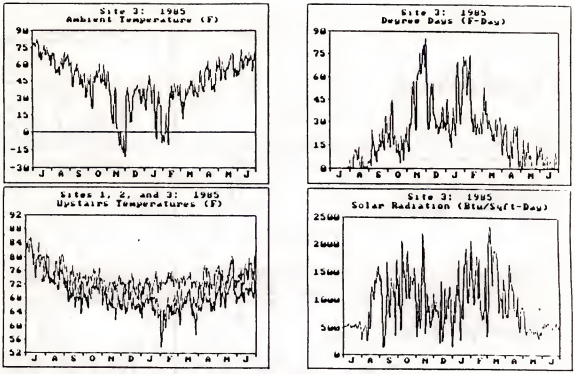
Site 3: 1985
Ambient Temperature (F)
Site 3: 1985
Degree Days (F-Day)
Sites 1, 2, and 3: 1985
Upstairs Temperatures (F)
Site 3: 1985
Solar Radiation (Btu/Sq(t-Day)
J A S O N D J F M A M J

FIG. 2. DAILY AMBIENT CONDITIONS AND INTERIOR TEMPERATURES DURING 1985.
The upper left plot shows ambient dry-bulb temperature for Site 3, while the upper right plot shows base 65 degree days. Both plots are dominated by two prolonged cold spells in Nov. and Feb. Daily average temperatures range from 87 to -20 F. The lower right plot shows daily total south vertical solar radiation. Because solar radiation shows extreme day to day variation the data were smoothed with weights (.25,.5,.25) to better show the main features. The two peaks during Oct. and late Feb. are due to the solar geometry at this latitude. The roof overhang totally shades direct radiation during May through mid-Aug. Thus the summer values consist only of diffuse radiation. This helps prevent overheating in the summer. The lower left plot shows average daily upstairs temperature at Sites 1,2 and 3. The temperatures range from 86 to 54 with large differences between sites.

Table 2. Data Summaries for All Sites, November 1985 through February 1986

Electricity Consumption (kWh)	Site 1	Site 2	Site 3	Site 4	Site 5
Upstairs Heat	1385	1584	2211	3104	3533
Basement Heat	1606	2825	2751	1548	3669
Total Heat	2991	4409	4962	4652	7202
Dryer	499	103	294	671	0
Water	1633	710	1912	1441	17
Other	4344	3158	3898	1975	492
Total Appliance	6476	3971	6104	4087	509
House Total	9467	8380	11066	8739	7711
Temperatures (F)					
Bedroom 1	65.6	68.1	72.2	69.5	66.6
Bedroom 2	65.5	70.0	71.1	68.1	67.0
Bedroom 3	66.1	70.8	71.7	68.6	68.2
Dining Room	66.7	72.5	71.3	67.5	68.0
Basement	66.3	71.9	70.0	60.7	66.2
Average House	66.5	70.7	71.7	66.8	67.2
Ambient	25.9	24.7	25.8	24.2	26.3
Average Delta	40.6	46.0	45.9	42.6	40.9
Hot Water (Gal/Day)	57.0	34.6	71.2	49.0	3
Vertical Solar (Btu/Sqft-Day)	926	871	963	942	761
Heating Degree Days (F-Day)	4693	4835	4701	4906	4639

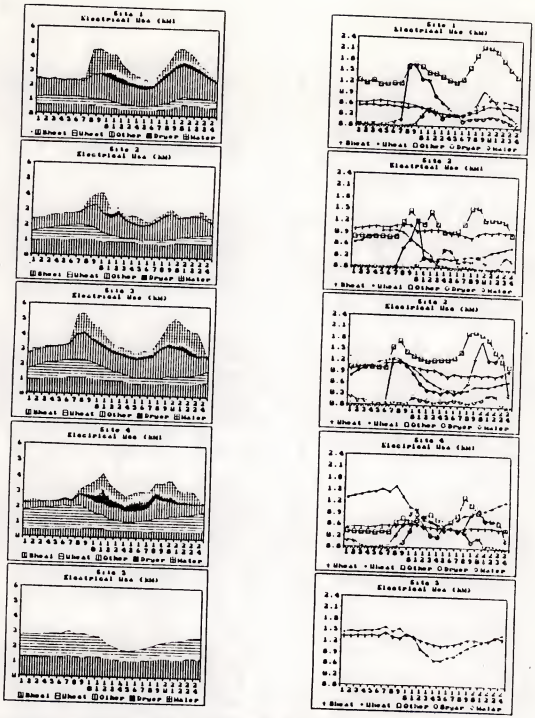

FIG. 4. END-USE PROFILES BY HOUR OF DAY FOR 1985-86 HEATING SEASON.
The left column shows the cumulative end-use consumption with Heat at the bottom followed by Other. The right column shows the individual end-use patterns each plotted at the same scale. At each of the occupied sites, the total consumption shows two peaks, one in the morning and one in the evening. The relative magnitudes, shape, and timing of these peaks varies from site to site. Site 2 is occupied by a retired couple who are home days, and shows a small peak at lunch time. Other is the largest load at all sites except Site 4. Upstairs space heat at Site 4 is large because the basement is unheated and the level of internal gains is low. The sum of Heat and Other at 6 AM is similar at all sites. The basement heat is nearly constant, while the upstairs heat shows a wider effect during the day. The large evening peak in Other at Site 1 is partially due to use of the hot tub.

APPENDIX G:

PRESSURE TESTING HOUSES FOR AIR LEAKAGE IN EASTERN MONTANA

RE: Fan Pressure Test Results
Site Tested: 1
Date Tested: April 8, 1986

Per the fan pressurization tests taken by Energy Inspection Technology of Butte, Montana, the house noted above tested as follows:

BUILDING ENVELOPE UNSEALED (Pressure/depressure Mean)

* Air changes per hour @ 50 pascals
pressure differential ---------- 1.15 ACH
* Effective leakage area (L.B.L. method) ---- 26.22 sq.in.
* Equivalent leakage area (Canadian method) -- 45.08 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) ----- 0.56.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.97 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.11 ACH
* Natural air infiltration - heating season
(November - March) ---------- 0.13 ACH

BUILDING ENVELOPE SEALED (Pressure/Depressure Mean)

* Air changes per hour @ 50 pascals
pressure differential ---------- 0.83 ACH
* Effective leakage area (L.B.L. method) ---- 18.28 sq.in.
* Equivalent leakage area (Canadian method) -- 31.69 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) --- 0.39 sq.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.68 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.08 ACH
* Natural air infiltration - heating season
(November - March) ---------- 0.09 ACH

SITE CONDITIONS

Wind speeds recorded on site were less than four miles per hour, temperature indoor 70F and outdoor 70F, and barometric pressure 30.11 in. Hg. The correlation coefficient being greater than 0.99 indicates a valid test. Relative humidity was measured as follows: 29% RH on main floor, 31% RH in the basement area, 37% RH in the room containing a hot tub with cover on, and 25% RH outdoors.

COMMENTS

The change in building tightness for the structure, while pressurized in both the sealed and unsealed modes, was insignificant based on comparing the recent fan pressurization measurements to those taken approximately one year ago.

RE: Fan Pressure Test Results
Site Tested: [8]
Date Tested: April 9, 1986

Per the fan pressurization tests taken by Energy Inspection Technology of Butte, Montana, the house noted above tested as follows:

BUILDING ENVELOPE UNSEALED (Pressure/depressure Mean)

* Air changes per hour @ 50 pascals pressure differential ---------- 1.22 ACH
* Effective leakage area (L.B.L. method) ---- 22.92 sq.in.
* Equivalent leakage area (Canadian method) -- 43.04 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) ----- 0.48.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.90 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.09 ACH
* Natural air infiltration - heating season (November - March) ---------- 0.11 ACH

BUILDING ENVELOPE SEALED (Pressure/Depressure Mean)

* Air changes per hour @ 50 pascals pressure differential ---------- 0.85 ACH
* Effective leakage area (L.B.L. method) ---- 12.76 sq.in.
* Equivalent leakage area (Canadian method) -- 26.01 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) --- 0.26 sq.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.54 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.05 ACH
* Natural air infiltration - heating season (November - March) ---------- 0.06 ACH

SITE CONDITIONS

Wind speeds recorded on site were less than four miles per hour, temperature indoor 71F and outdoor 49F-54F, and barometric pressure 30.01 in. Hg. The correlation coefficient being greater than 0.99 indicates a valid test. Relative humidity was measured as follows: 31% RH on main floor, 31% RH in the basement area, and 50% RH outdoors.

COMMENTS

The change in building tightness for the structure, while pressurized in both the sealed and unsealed modes, was insignificant based on comparing the recent fan pressurization measurements to those taken approximately one year ago.

RE: Fan Pressure Test Results
Site Tested: 3
Date Tested: April 8, 1986

Per the fan pressurization tests taken by Energy Inspection Technology of Butte, Montana, the house noted above tested as follows:

BUILDING ENVELOPE UNSEALED (Pressure/depressure Mean)

* Air changes per hour @ 50 pascals pressure differential ---------- 1.85 ACH
* Effective leakage area (L.B.L. method) ---- 35.09 sq.in.
* Equivalent leakage area (Canadian method) -- 64.47 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) ----- 0.74.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 1.36 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.12 ACH
* Natural air infiltration - heating season (November - March) ---------- 0.15 ACH

BUILDING ENVELOPE SEALED (Pressure/Depressure Mean)

* Air changes per hour @ 50 pascals pressure differential ---------- 1.41 ACH
* Effective leakage area (L.B.L. method) ---- 24.12 sq.in.
* Equivalent leakage area (Canadian method) -- 46.00 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) --- 0.51 sq.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.97 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.04 ACH
* Natural air infiltration - heating season (November - March) ---------- 0.05 ACH

SITE CONDITIONS

Wind speeds recorded on site were less than four miles per hour, temperature indoor 74F and outdoor 69F, and barometric pressure 30.11 in. Hg. The correlation coefficient being greater than 0.99 indicates a valid test. Relative humidity was measured as follows: 29% RH on main floor, 39% RH in the basement area, and 28% RH outdoors.

COMMENTS

The change in building tightness for the structure during the pressure tests in both the sealed and unsealed mode was an increase based on comparing the recent fan pressurization measurements to those taken approximately one year ago. Since the last pressure test the occupant has added a large room and attached garage to the main structure. Per the contractor/occupant, the common wall was left in tact so as not to disrupt the air vapor barrier. However, installation of the wiring to the these areas and grounding wire for the garage required penetrating the AVB. Although many of the air leakage points identified during the last tests had been sealed, there were a number of bypasses (old and new) contributing to the leakage, especially in the basement utility area and unfinished basement.

RE: Fan Pressure Test Results
Site Tested: 4
Date Tested: April 9, 1986

Per the fan pressurization tests taken by Energy Inspection Technology of Butte, Montana, the house noted above tested as follows:

BUILDING ENVELOPE UNSEALED (Pressure/depressure Mean)

* Air changes per hour @ 50 pascals pressure differential ---------- 1.03 ACH
* Effective leakage area (L.B.L. method) ---- 16.03 sq.in.
* Equivalent leakage area (Canadian method) -- 30.39 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) ----- 0.34.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.65 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.06 ACH
* Natural air infiltration - heating season (November - March) ---------- 0.07 ACH

BUILDING ENVELOPE SEALED (Pressure/Depressure Mean)

* Air changes per hour @ 50 pascals pressure differential ---------- 0.66 ACH
* Effective leakage area (L.B.L. method) ---- 8.95 sq.in.
* Equivalent leakage area (Canadian method) -- 17.76 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) --- 0.19 sq.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.38 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.03 ACH
* Natural air infiltration - heating season (November - March) ---------- 0.04 ACH

SITE CONDITIONS

Wind speeds recorded on site were light and variable at two to six miles per hour, temperature indoor 68F and outdoor 64F, and barometric pressure 25.73 in. Hg. The correlation coefficient being greater than 0.99 indicates a valid test. Relative humidity was measured as follows: 39% RH on main floor, 41% RH in the basement area, and 39% RH outdoors.

COMMENTS

The change in building tightness for the structure during the pressure tests in both the sealed and unsealed mode was a slight increase based on comparing the recent fan pressurization measurements to those taken approximately one year ago.

RE: Fan Pressure Test Results
Site Tested: [5]
Date Tested: April 10, 1986

Per the fan pressurization tests taken by Energy Inspection Technology of Butte, Montana, the house noted above tested as follows:

BUILDING ENVELOPE UNSEALED (Pressure/depressure Mean)

* Air changes per hour @ 50 pascals pressure differential ---------- 1.31 ACH
* Effective leakage area (L.B.L. method) ---- 25.95 sq.in.
* Equivalent leakage area (Canadian method) -- 46.23 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) ----- 0.56.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.99 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.10 ACH
* Natural air infiltration - heating season (November - March) ---------- 0.12 ACH

BUILDING ENVELOPE SEALED (Pressure/Depressure Mean)

* Air changes per hour @ 50 pascals pressure differential ---------- 0.83 ACH
* Effective leakage area (L.B.L. method) ---- 12.13 sq.in.
* Equivalent leakage area (Canadian method) -- 24.54 sq.in.
* Correlation coefficient ----------) 0.99
* Leakage ratio (L.B.L. method) --- 0.26 sq.in./100 sq.ft.
* Leakage ratio (Canadian method) -- 0.53 sq.in./100 sq.ft.
* Natural air infiltration - annual mean -------- 0.05 ACH
* Natural air infiltration - heating season (November - March) ---------- 0.05 ACH

SITE CONDITIONS

Wind speeds recorded on site were light and variable ranging between two and nine miles per hour, temperature indoor 66F and outdoor 50F, and barometric pressure 29.89 in. Hg.. The correlation coefficient being greater than 0.99 indicates a valid test. Relative humidity was measured as follows: 39% RH on main floor, 41% RH in the basement area, and 39% RH outdoors.

COMMENTS

The change in building tightness for the structure during the pressure tests was a slight increase in the unsealed mode while the difference when sealed was insignificant based on comparing the recent fan pressurization measurements to those taken approximately one year ago.

APPENDIX H:

AIR FLOW MEASUREMENTS FROM THE MONTANA SUPERINSULATION PROJECT

Note 8, cont.

range between high and low, and reduce the flow rate at low speed without reducing the overall ventilation capability at high speed. (Why can't someone come up with a speed controller, perhaps by going to direct current controller and fans, that will give me as a designer the ability to spec a machine that's capable of infinite speed control between zero and two air changes per hour?!)

NOTE 9

My sense, pending further advice from Van EE, is that I will be able to go back to sites 1,2, and 3 and reduce the low speed voltages to about 55 volts as well, with a resultant change in flows, especially at low speed for these sites that resembles the comparison between set 7 and 8 for sites 4 and 5.

When this is accomplished, I predict we'll see a maximum flow in sites 1 and 2 (which are of concern in the "Phase 2" monitoring program), of around 153 cfm, and a minimum flow on low speed in the neighborhood of 110 to 120 cfm. Of note with respect to these numbers, if they prove to be real, is the fact that the respective pressures seen at these flows is likely to be in the range of .045" w.c. or .055" w.c. on the low end, and .090" w.c. on the upper end. This information formed the basis of my input to decisions about the selection of, and proper range choice of, the pressure transducer for our upcoming monitoring effort.

RJC/kb

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REFERENCES

The following is a partial listing of published and unpublished reports and papers that are of use in either gaining a more complete understanding of the Montana Superinsulation Project, (MSIP) or were used in the course of this work. Items marked with an asterisk (*) are published in proceedings from "Conservation in Building: Northwest Perspective," a May 1986 conference which was also an outgrowth of the MSIP, and was produced by NCAT.

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